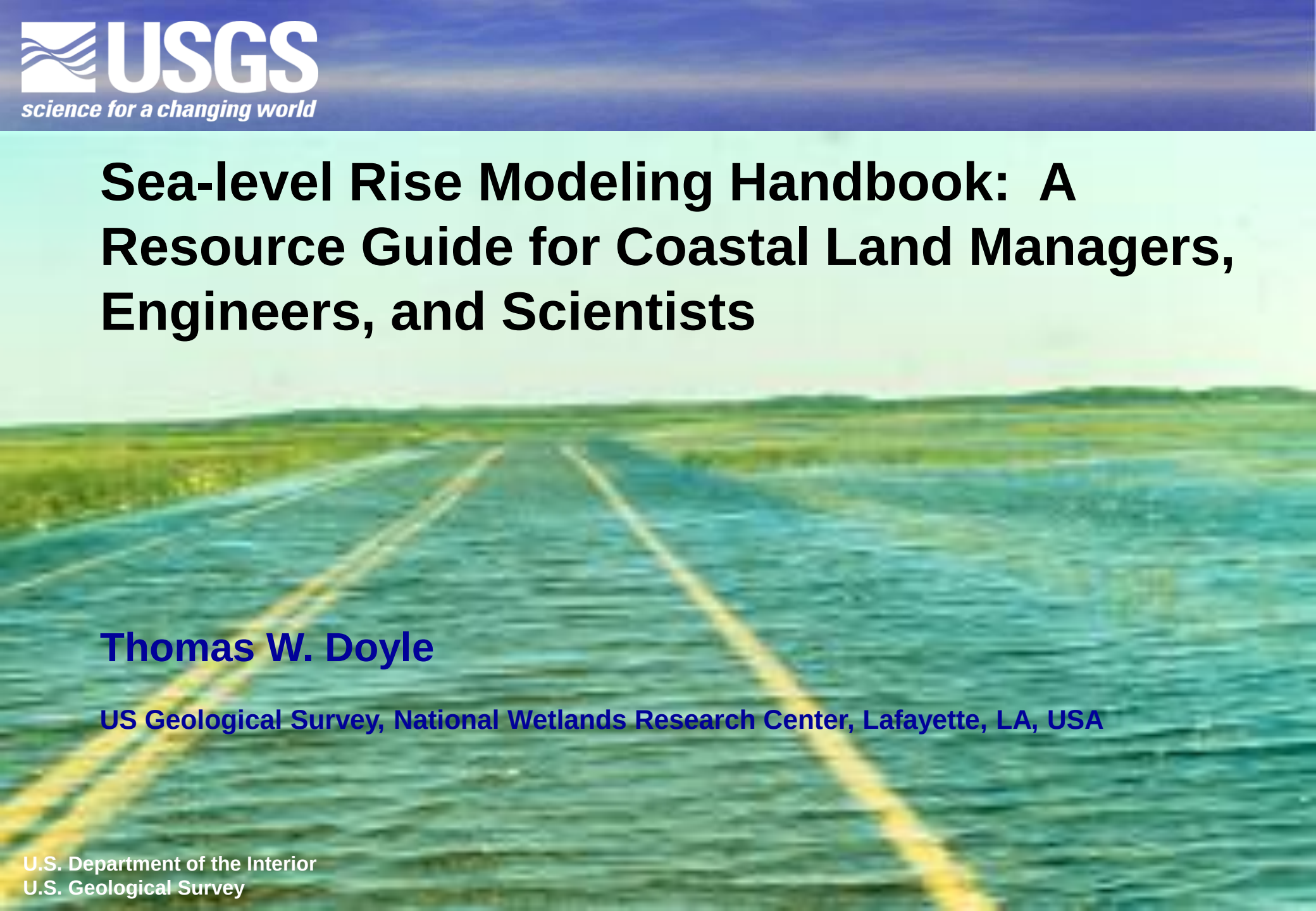
USGS
science for a changing world

Sea-level Rise Modeling Handbook: A Resource Guide for Coastal Land Managers, Engineers, and Scientists



Thomas W. Doyle

US Geological Survey, National Wetlands Research Center, Lafayette, LA, USA

U.S. Department of the Interior
U.S. Geological Survey

SLR Handbook Outline

- **Understanding Sea-Level Change**
  - Methods for Reconstructing and Observing SLR
- **Predicting Sea-Level Rise Impacts**
  - Models for Simulating SLR Effects on Ecosystems

USGS

Understanding Sea-Level Change

- **Earth's Hydrosphere**
  - Volume Static
  - Form Dynamic
- **Reconstructing Sea-Level History**
  - Effects of Plate Tectonics (Size of Ocean Basins)
  - Effects of Glaciation (Orbital Cycles)
  - Holocene Sea-Level Rise (Since Last Glacial Maximum)
- **Contemporary Sea-Level Record**
  - Long-term Tide Gage Relative Sea-Level Rise
  - Satellite Sea-Surface Height Observations
  - Land Motion and Subsidence/Uplift
- **Future Sea-Level Projections**

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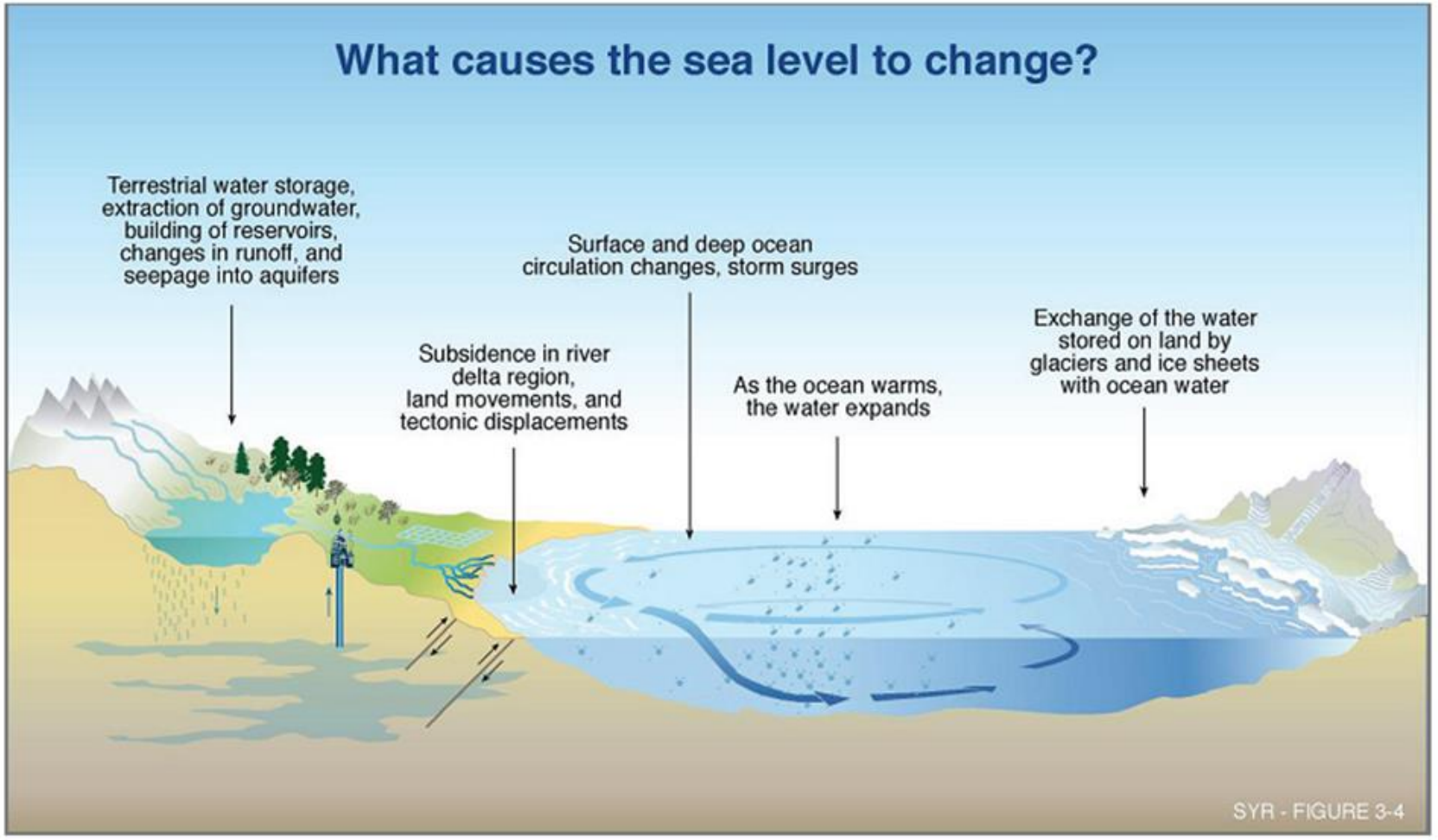
Earth's Hydrosphere



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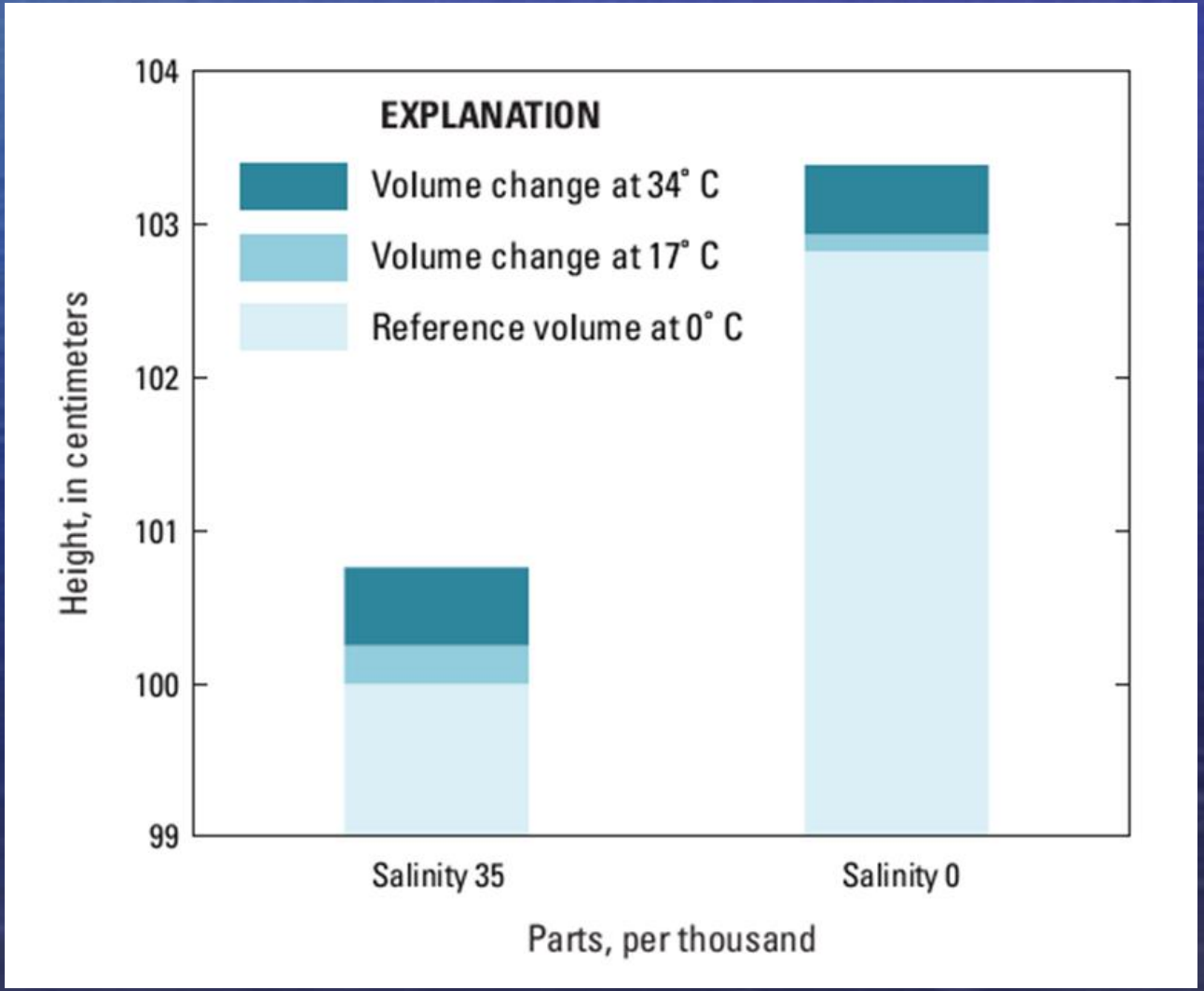
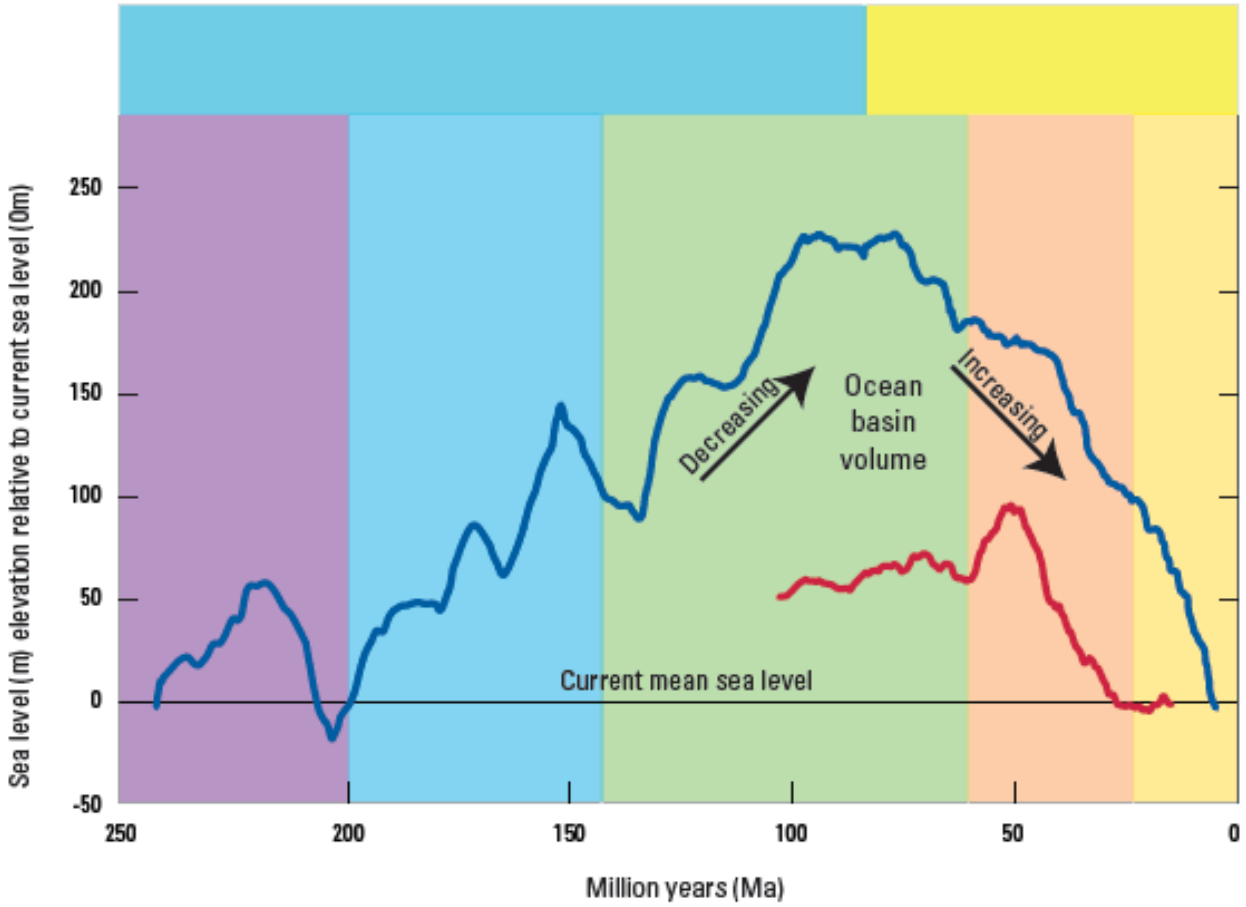
Temperature Effect on Water Expansion



USGS

Effects of Plate Tectonics



EXPLANATION

101-point moving average (Haq and others, 1987 data)

10 mil yrs moving average (Kominz et al. 2008 data)

Era

Mesozoic

Cenozoic

Period

Triassic (252–201 million years)

Jurassic (201–145 million years)

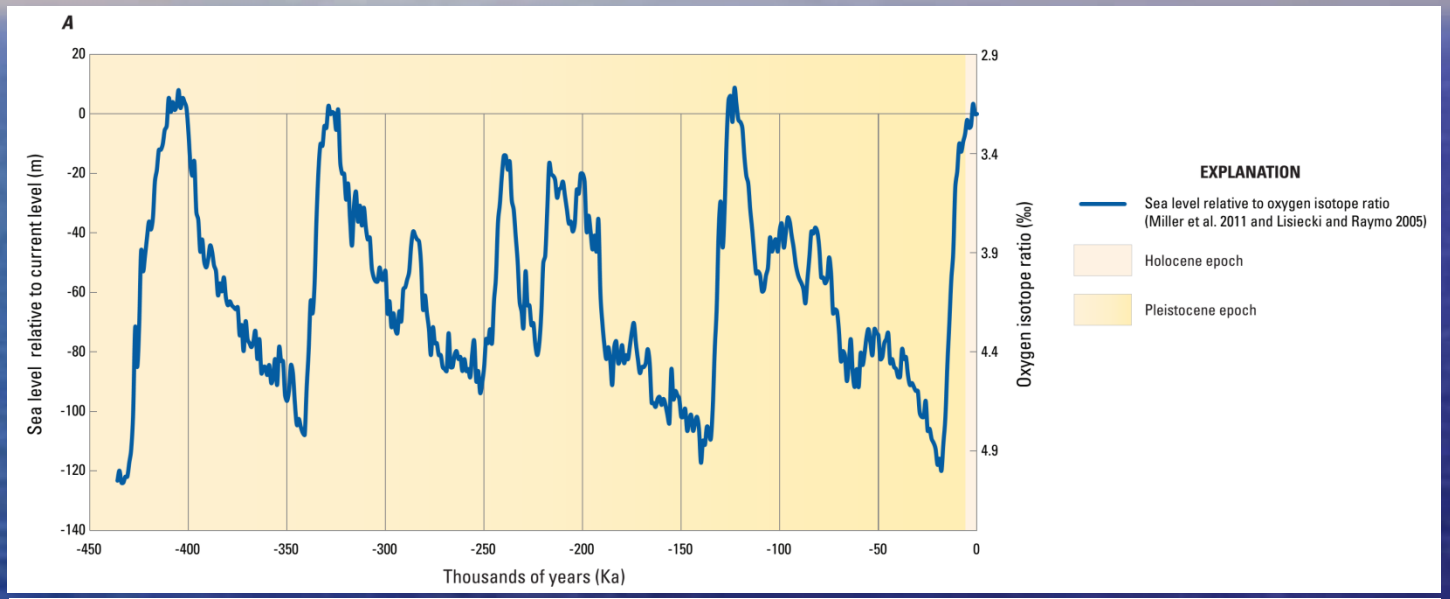
Cretaceous (145–66 million years)

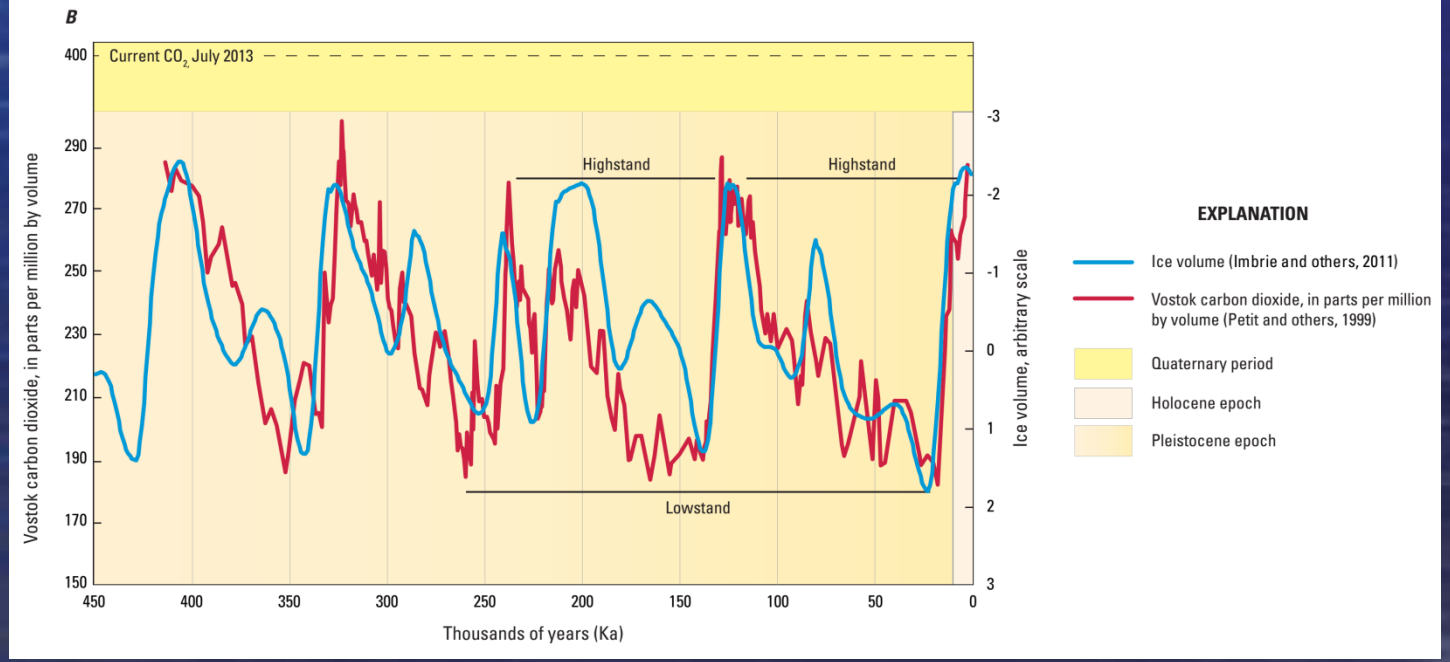
Paleogene (66–23 million years)

Neogene (23–2.6 million years)

USGS

Effects of Glaciation

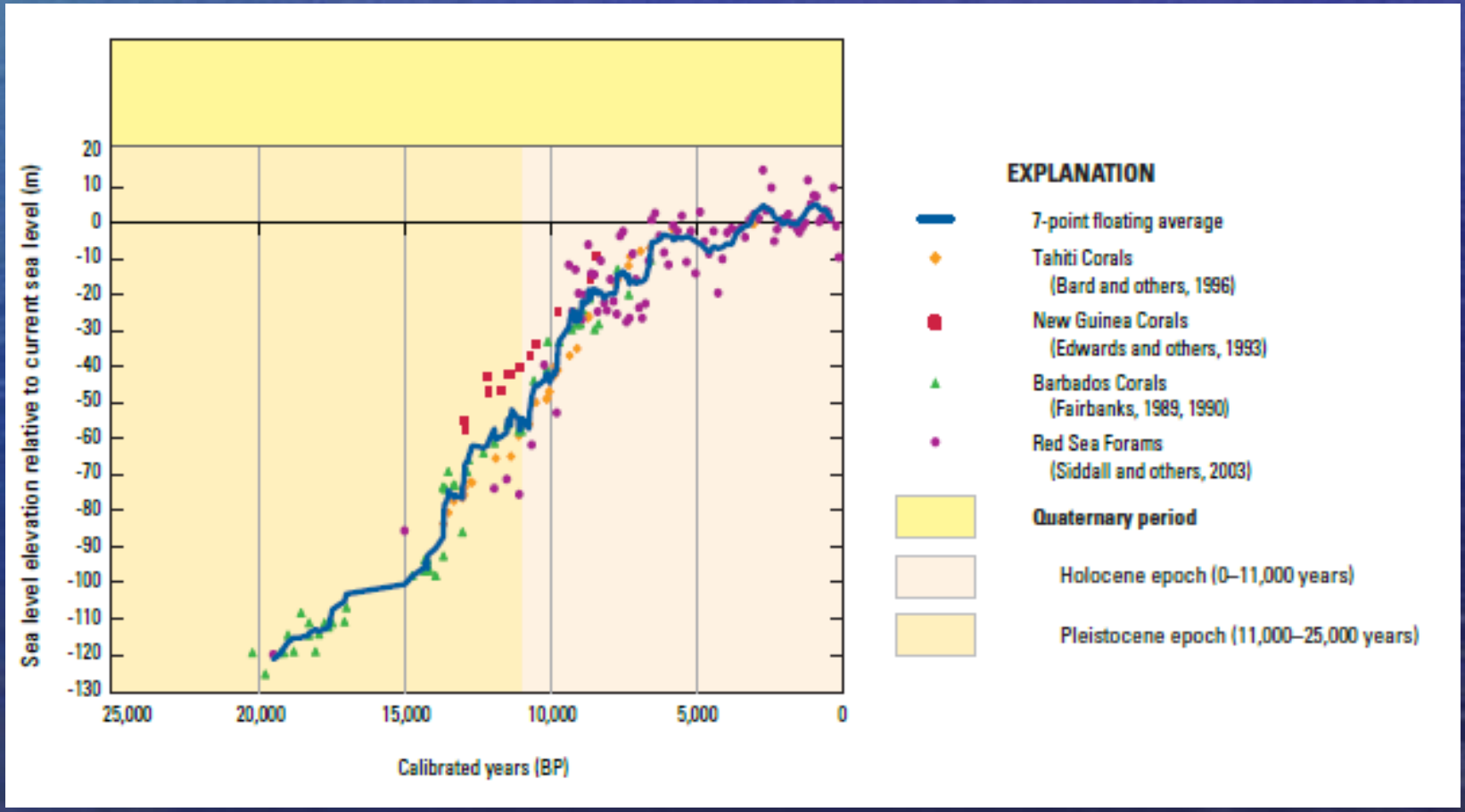




USGS

Holocene Sea-Level Rise

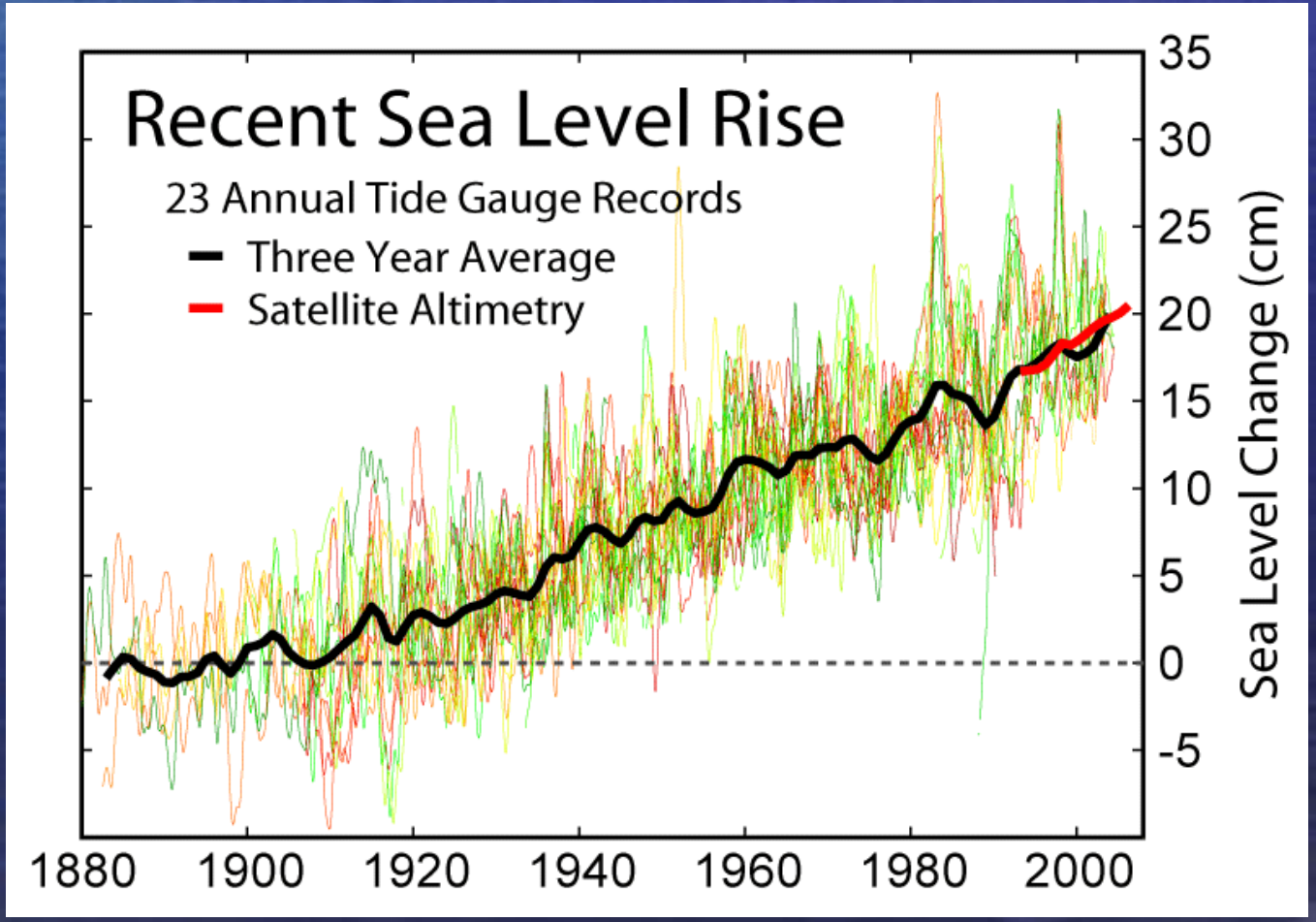
Balsillie and Donoghue 2004



USGS

Contemporary Sea-Level Rise

Sea level measurements from 23 long tide gauge records in geologically stable environments show a rise of around 20 centimeters per century (2 mm/year). Source: IPCC 2001



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Relative Mean Sea-Level Rise

- RSLR = Relative Sea-Level Rise
- RSLR = *f*(Δ sea level + Δ land surface elevation)
- Δ Sea height = *f*(eustacy, gravity, winds, waves, etc.)
- Δ Land height = *f*(subsidence, deposition, erosion, etc.)

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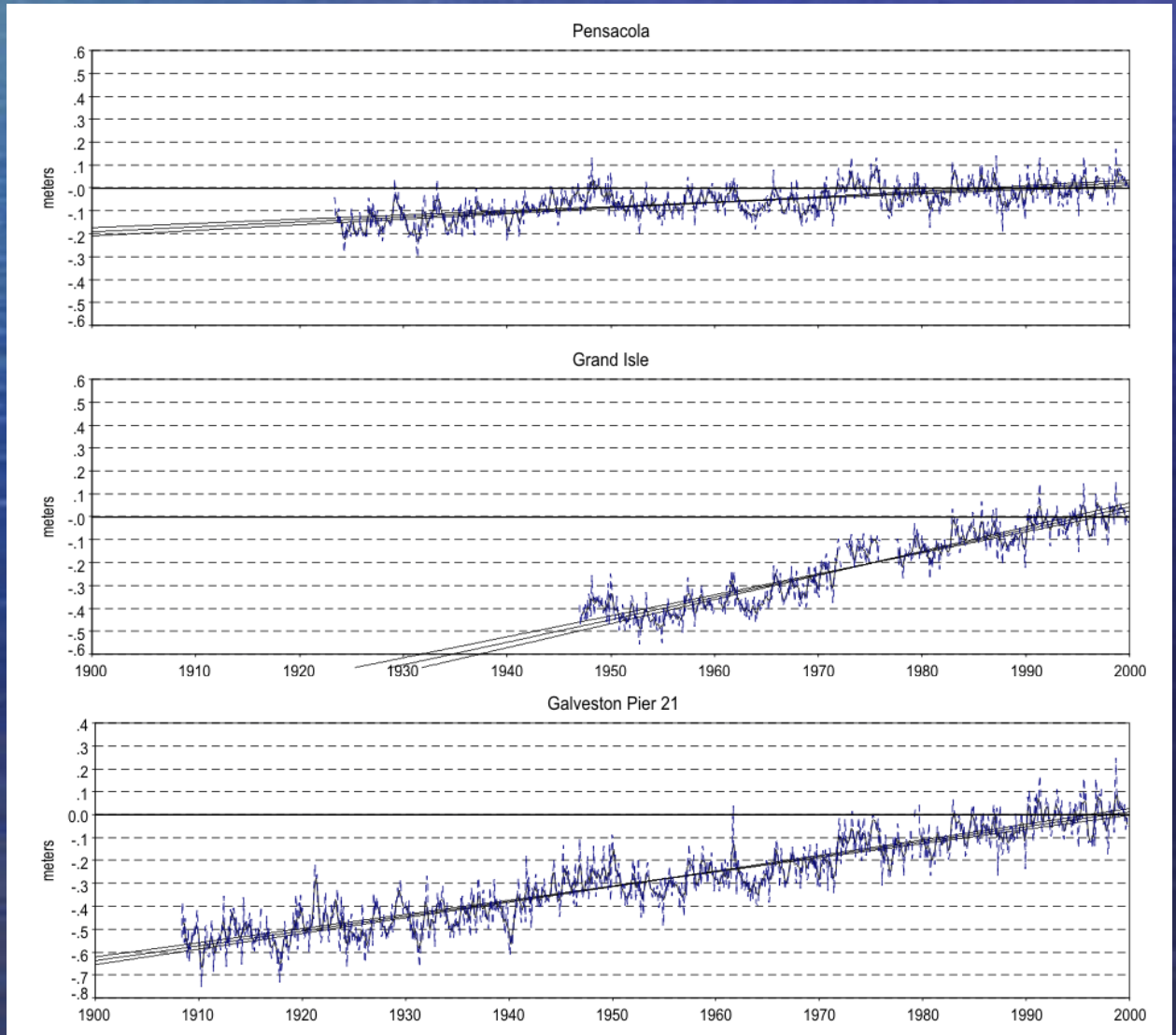
Relative Sea-level Rise for Gulf Coast USA

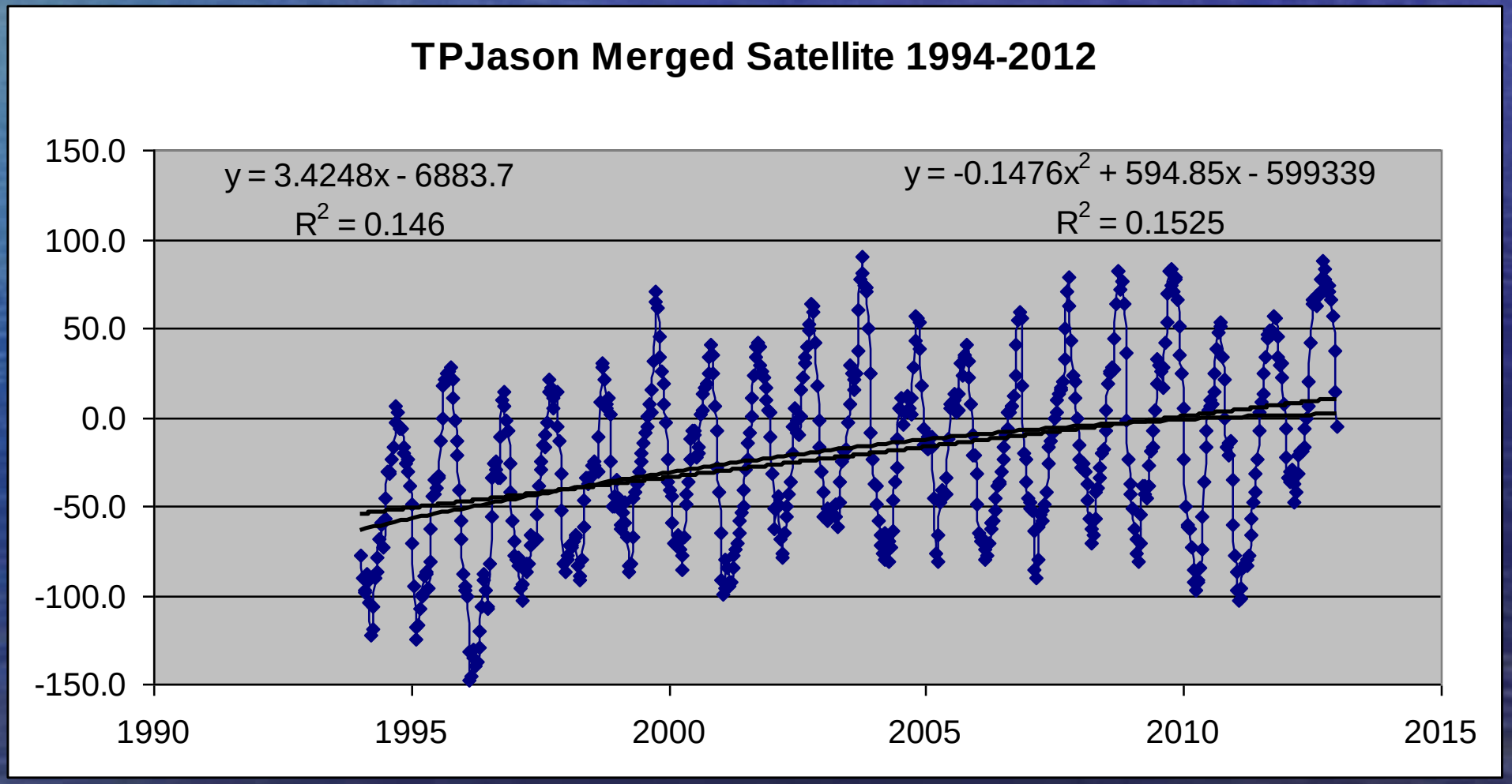


RSLR=2.14mm/yr
RSLR=2.10mm/yr
Pensacola, FL
Stable Geology

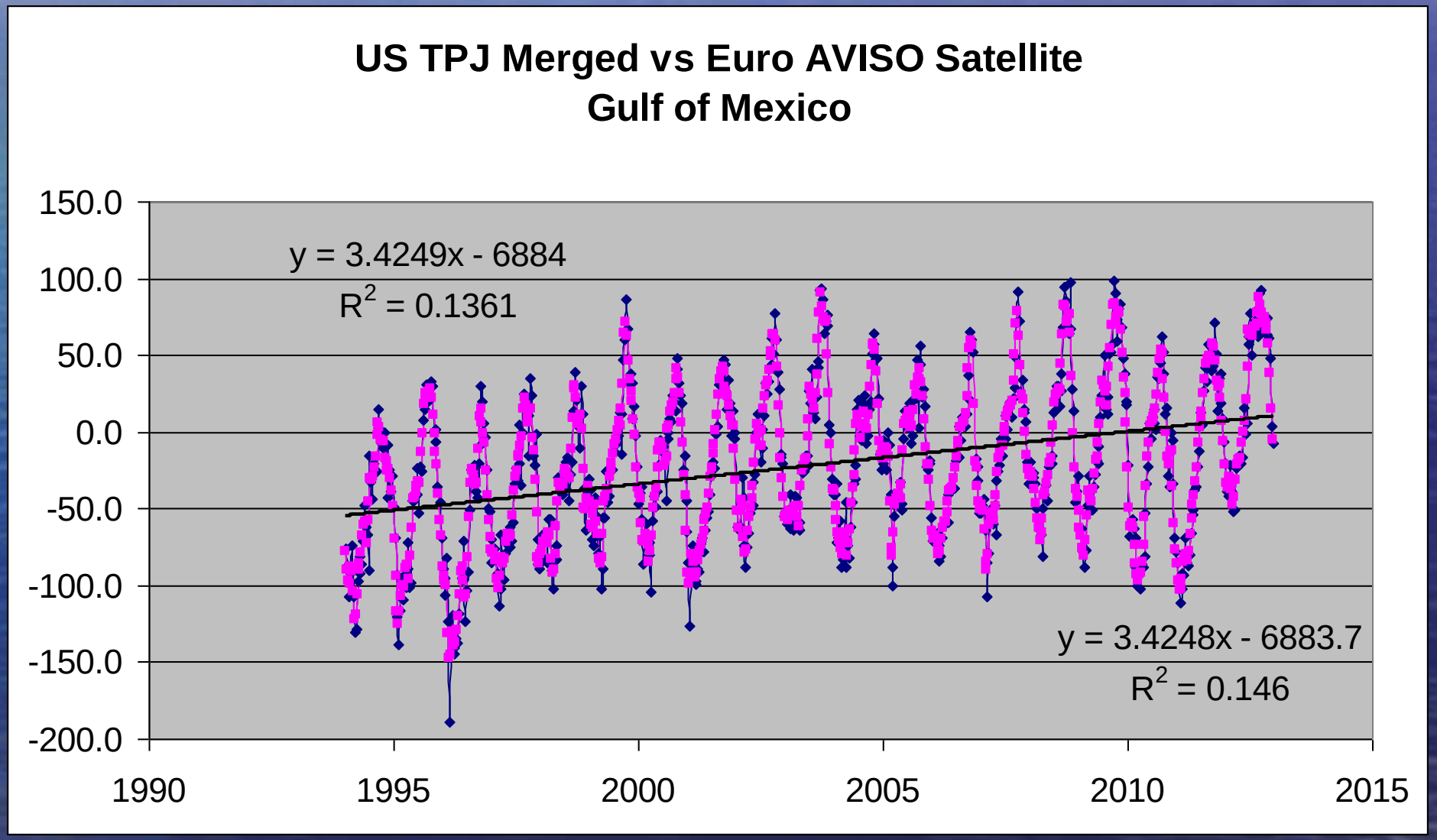
RSLR=9.85mm/yr
RSLR=9.24mm/yr
Grand Isle, LA
Deltaic Plain

RSLR=6.5 mm/yr
RSLR=6.4 mm/yr
Galveston, TX
Chenier Plain

US Topex/Poseidon/Jason Satellite Records



USGS


US TPJ Merged vs Euro AVISO Satellite
Gulf of Mexico
y = 3.4249x - 6884
R2 = 0.1361
y = 3.4248x - 6883.7
R2 = 0.146
150.0
100.0
50.0
0.0
-50.0
-100.0
-150.0
-200.0
1990
1995
2000
2005
2010
2015

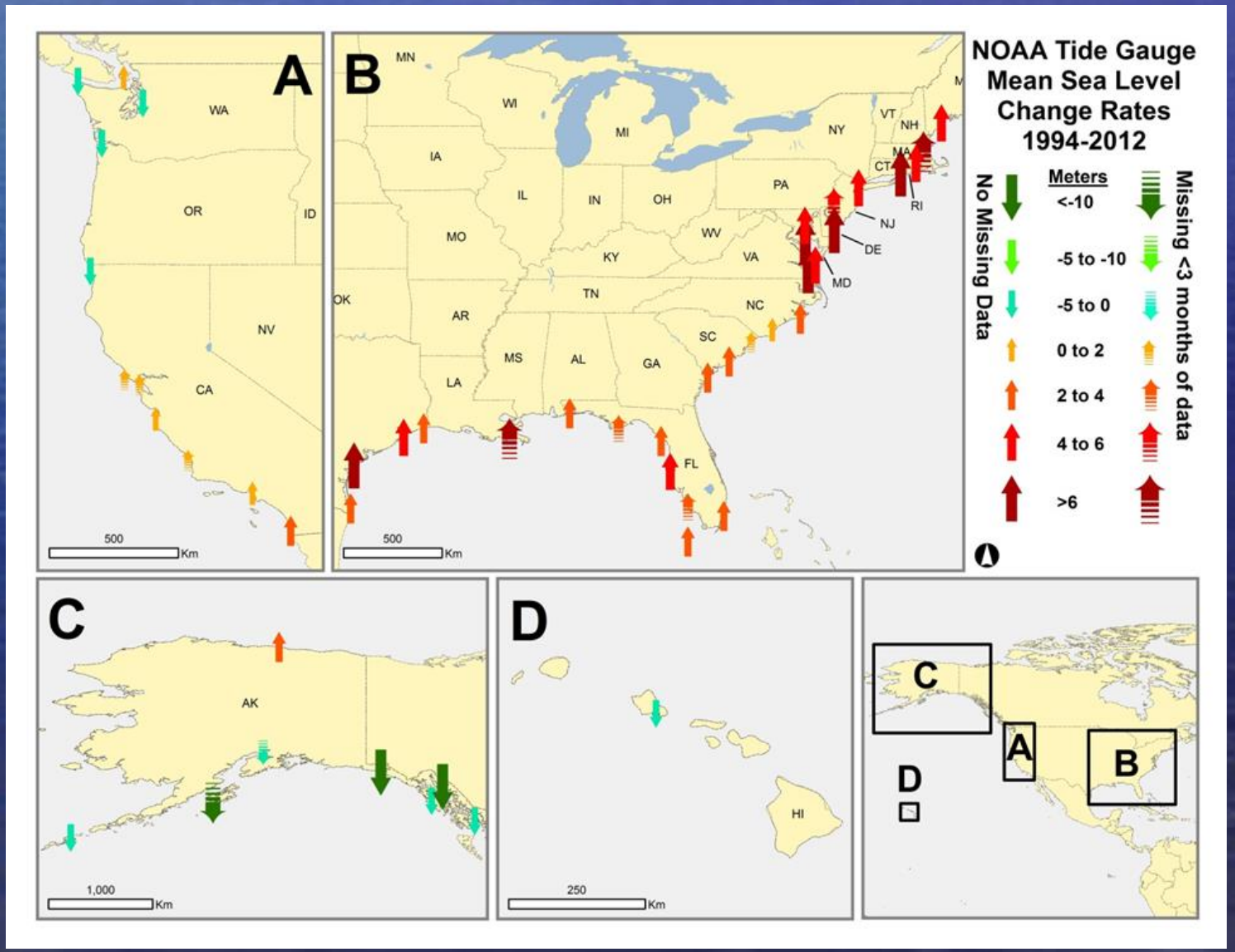
Modeling and Comparing SLR Trends

Tide Gage vs Satellite Records

- Rectifying to the Same Datum!
- Comparing the Same Time Periods!
- Complete Records - No Data Gaps!

USGS

U.S. Tide Gage Relative SLR Trends Satellite Era (1994-2012)



USGS

Satellite vs Tide Gages 1994-2012

Observation Platform Location	SLR Trend (1994-2012) mm/yr	Residual Land Motion mm/yr
U.S. Topex/Poseidon/Jason	3.32*	-
European AVISO	3.32*	-
Key West, FL gage	4.42	1.10
Pensacola, FL gage	4.92	1.60
Grand Isle, LA gage	7.34	4.02
Galveston, TX gage	5.87	2.55

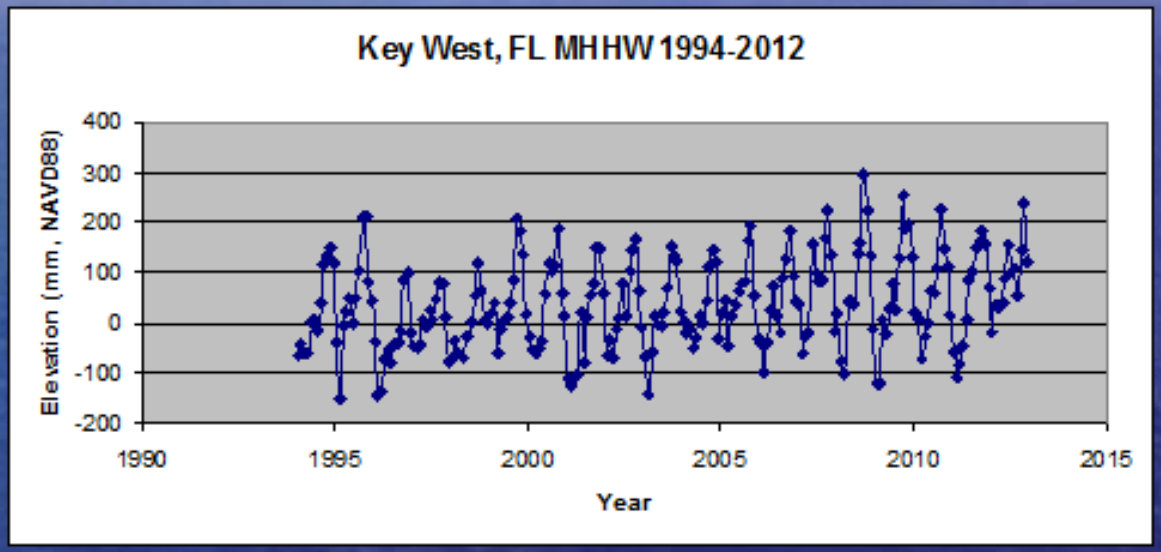
USGS

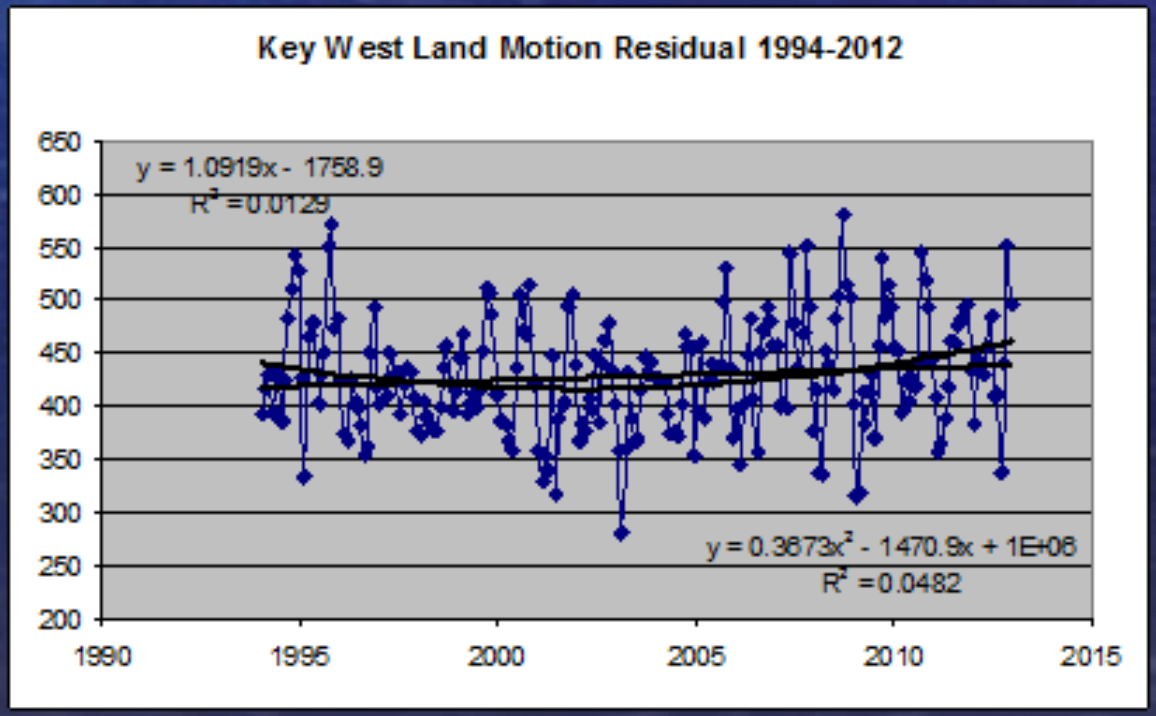
Tide Gage SLR for earlier Tidal Epochs

Tide Gage Location City, State	1918-1936	1937-1956	1957-1974	1975-1993	1994-2012
KeyWest, FL	Missing data	4.20	5.38	3.02	4.42
Pensacola, FL	Missing data	4.06	3.87	4.33	4.92
Galveston, TX	4.56	6.91	10.40	8.23	5.87
** Grand Isle					7.34

USGS

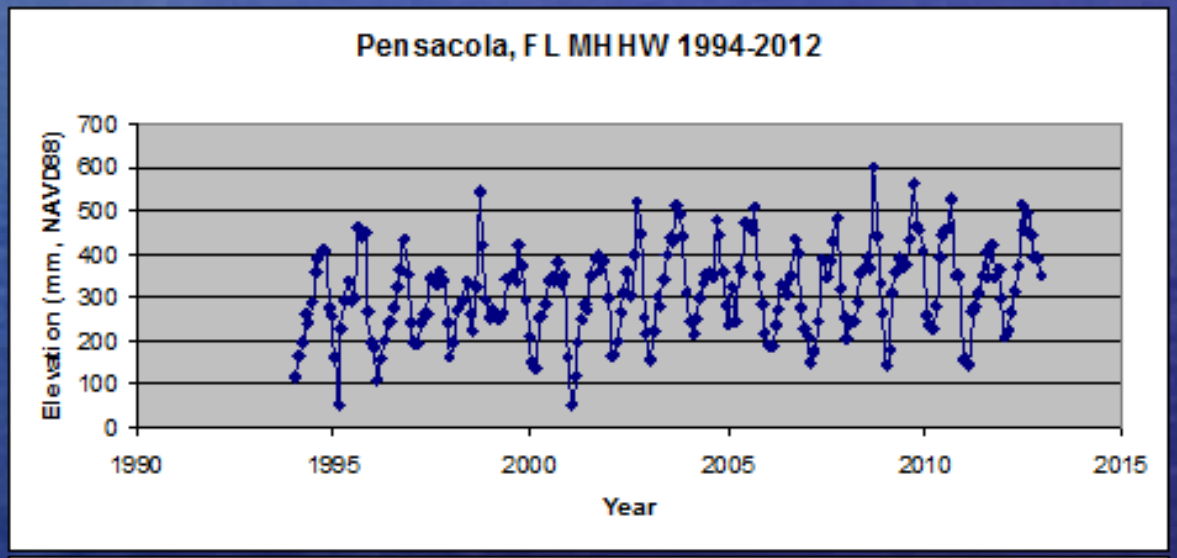
Key West, FL Gage vs Satellite

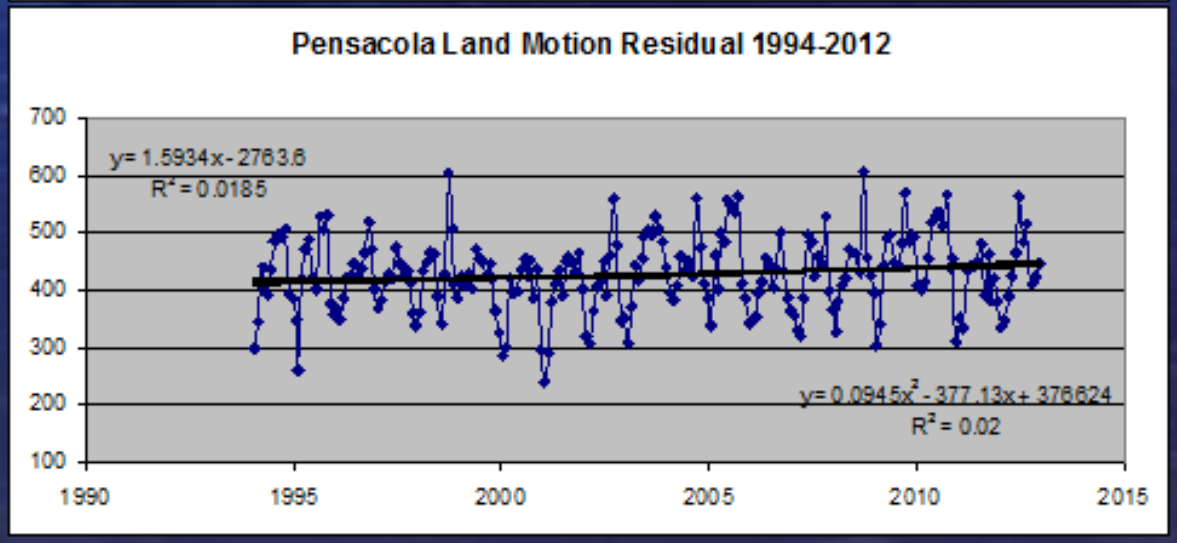




USGS

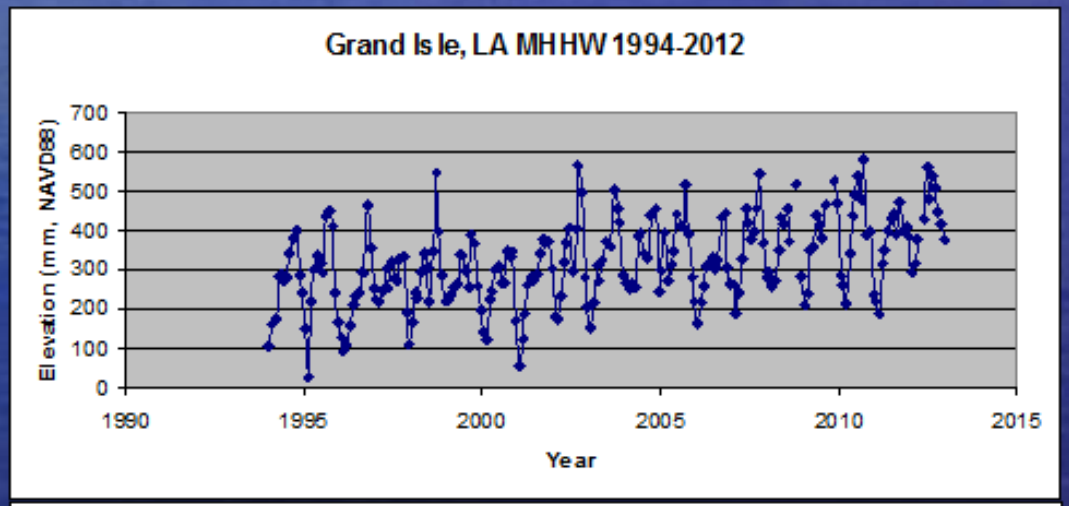
Pensacola, FL Gage vs Satellite

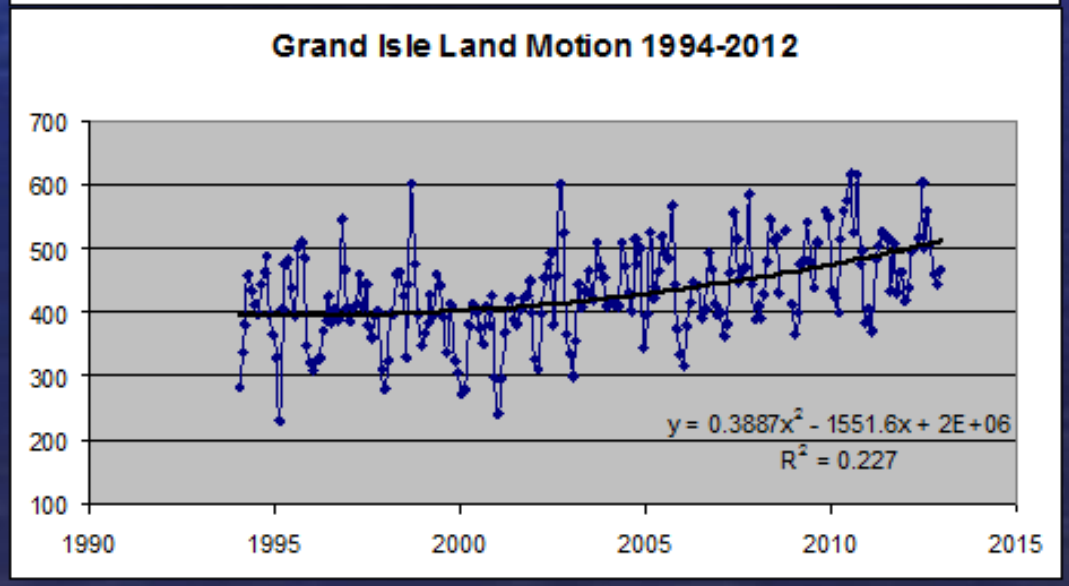




USGS

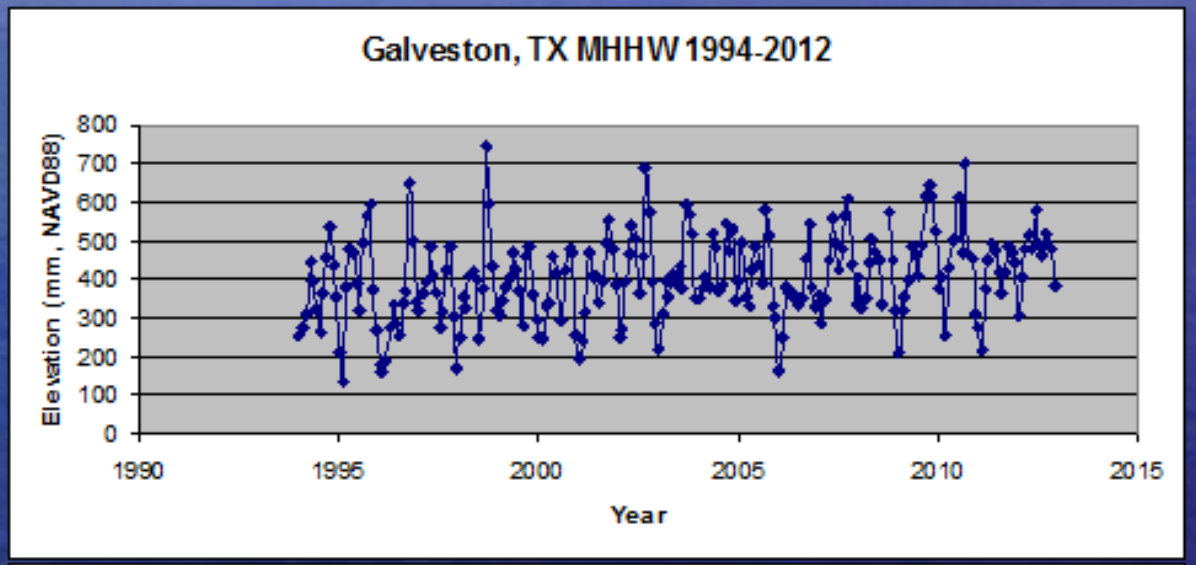
Grand Isle, LA Gage vs Satellite

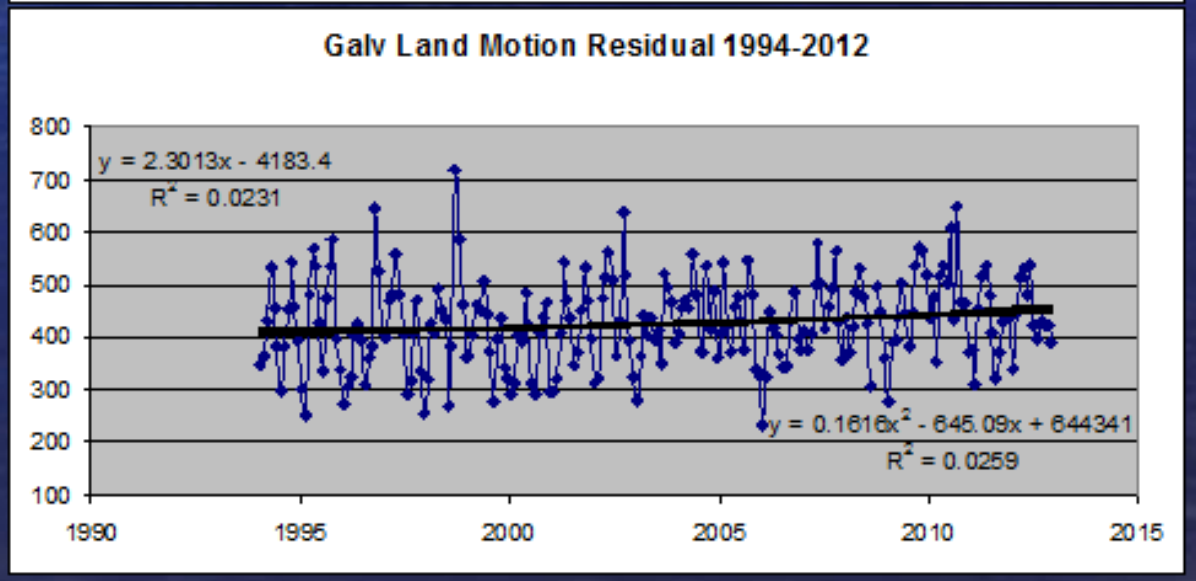




USGS

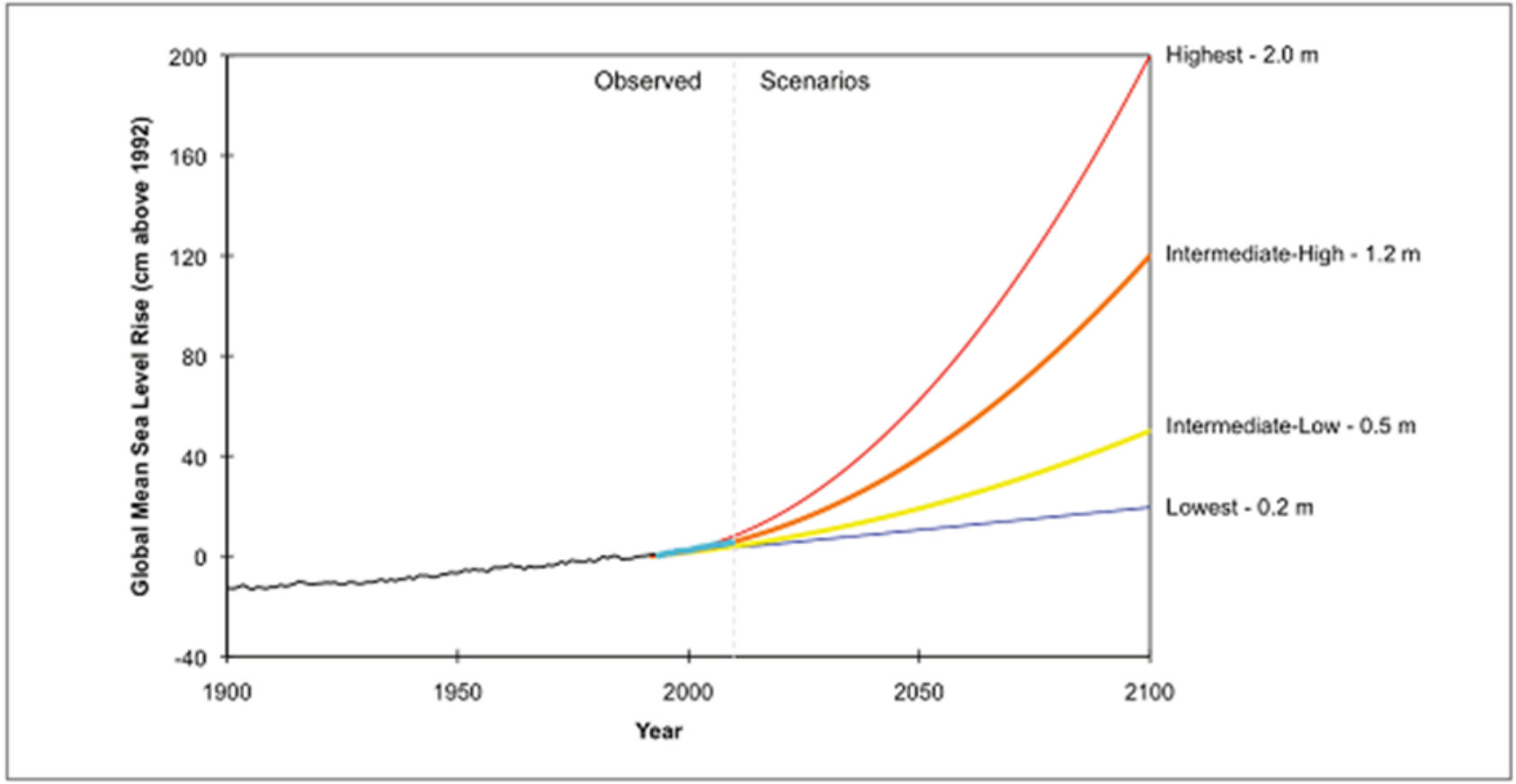
Galveston, TX Gage vs Satellite





USGS

National Climate Assessment 2012
Future Sea-level Rise Projections



USGS

Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program, 841 pp. doi:10.7930/J0Z31WJ2.

Predictive Models of Sea-Level Rise

- Sea-level Rise Simulation and Inundation Models
- GIS Sea-level Rise Mapping Tools
- Wetland Change Models
- Surface Elevation and Shoreline Erosion Models
- Niche-Based Species Distribution Models
- Leaf to Landscape Ecosystem Models

USGS

Sample Table Layout of Model Descriptions

Table 3. Sea-Level Rise Simulation and Inundation Model attributes							
Model	Agency /Organization	Appropriate scale	Spatial resolution	Temporal scale	Input parameters	Output parameters	Citations
CoastCLIM Sea-level Simulator (component of the SimCLIM system)	CLIMsystems	Local, regional, global	Varies, determined by data availability and computation demands	Variable depending on impact model being run	Elevation, climatologies, site time-series data, patterns of climate and sea-level changes from GCMs, impact models	Maps of areas/habitats potentially vulnerable to inundation. May estimate adaptation costs.	Warrick 2006; Warrick and Cox 2007
NOAA Inundation Frequency Analysis	NOAA	Local	Not applicable	1 month - 5 years	Tide station, reference elevation, date range	Inundation duration, frequency of high water elevation or duration (tabular or graph format)	http://tidesandcurrents.noaa.gov/inundation/, Inundation Analysis Users' Guide
SLRRP Sea-Level Rectification Program	U.S. Geological Survey	Local, regional	Not applicable	Historic tide range + projection to 2100, monthly to annual time step	Tide station, local subsidence rate (historic or custom), GCM sea-level rise rate	Cumulative sea-level rise, flood inundation potential for given elevation	Keim et al. 2008
Temperature-based Sea-Level Rise Model	Potsdam Institute for Climate Impact Research	Global	Not applicable	1990-2100	Global mean sea level, mean temperature, time	Future mean sea level	Rahmstorf 2007

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Sea-level Rise Simulation and Inundation Models

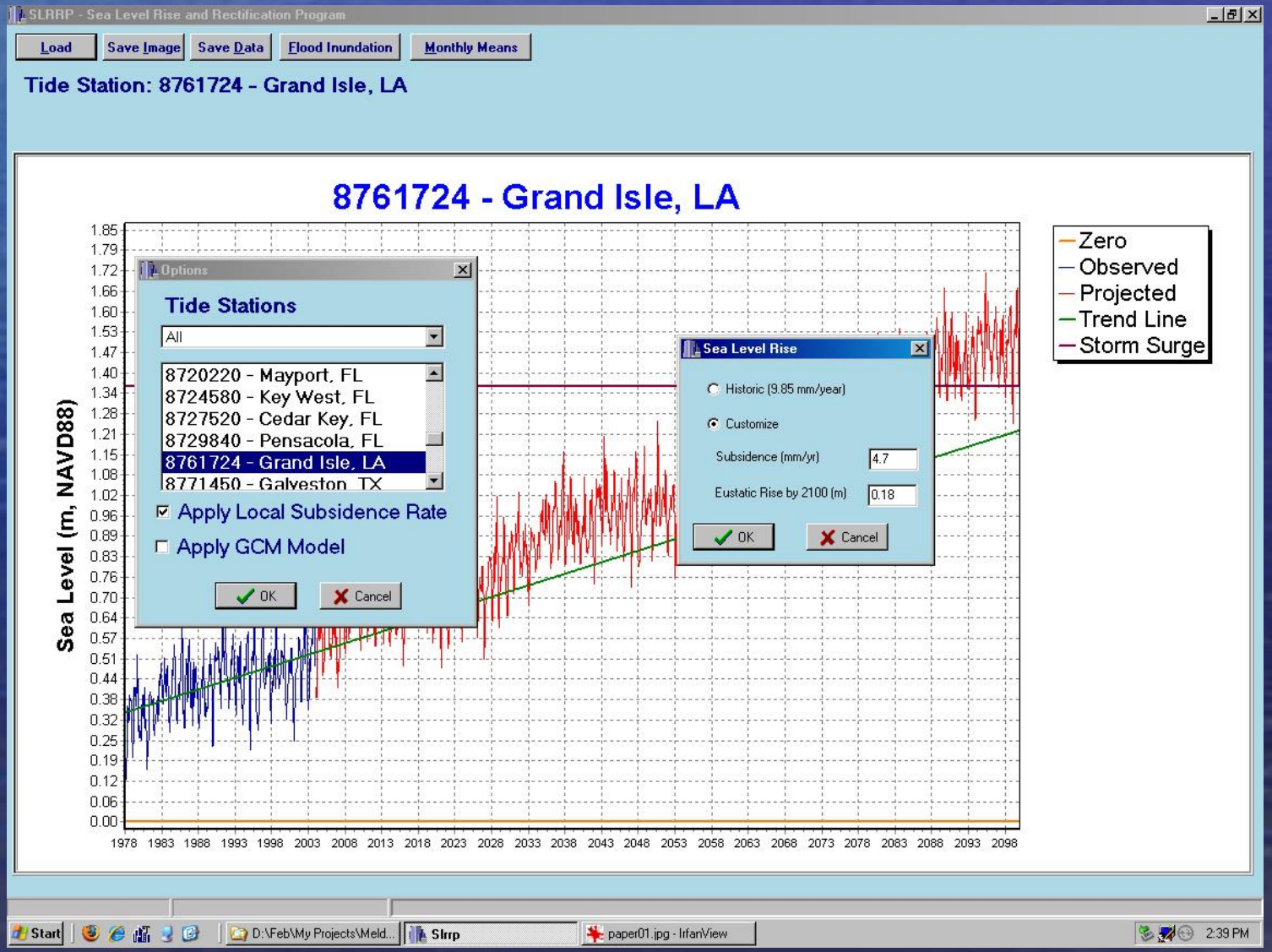
- CoastCLIM
- NOAA Inundation Frequency Analysis
- **SLRRP, Sea-level Rise Rectification Program**
- Temperature-based SLR Projections
- Soil Salinity Models
- Expert Hydrodynamic Engineering Models

  HECRAS, Delft3D, MikeII, Mike3FM, SLOSH, ADCIRC, …

USGS

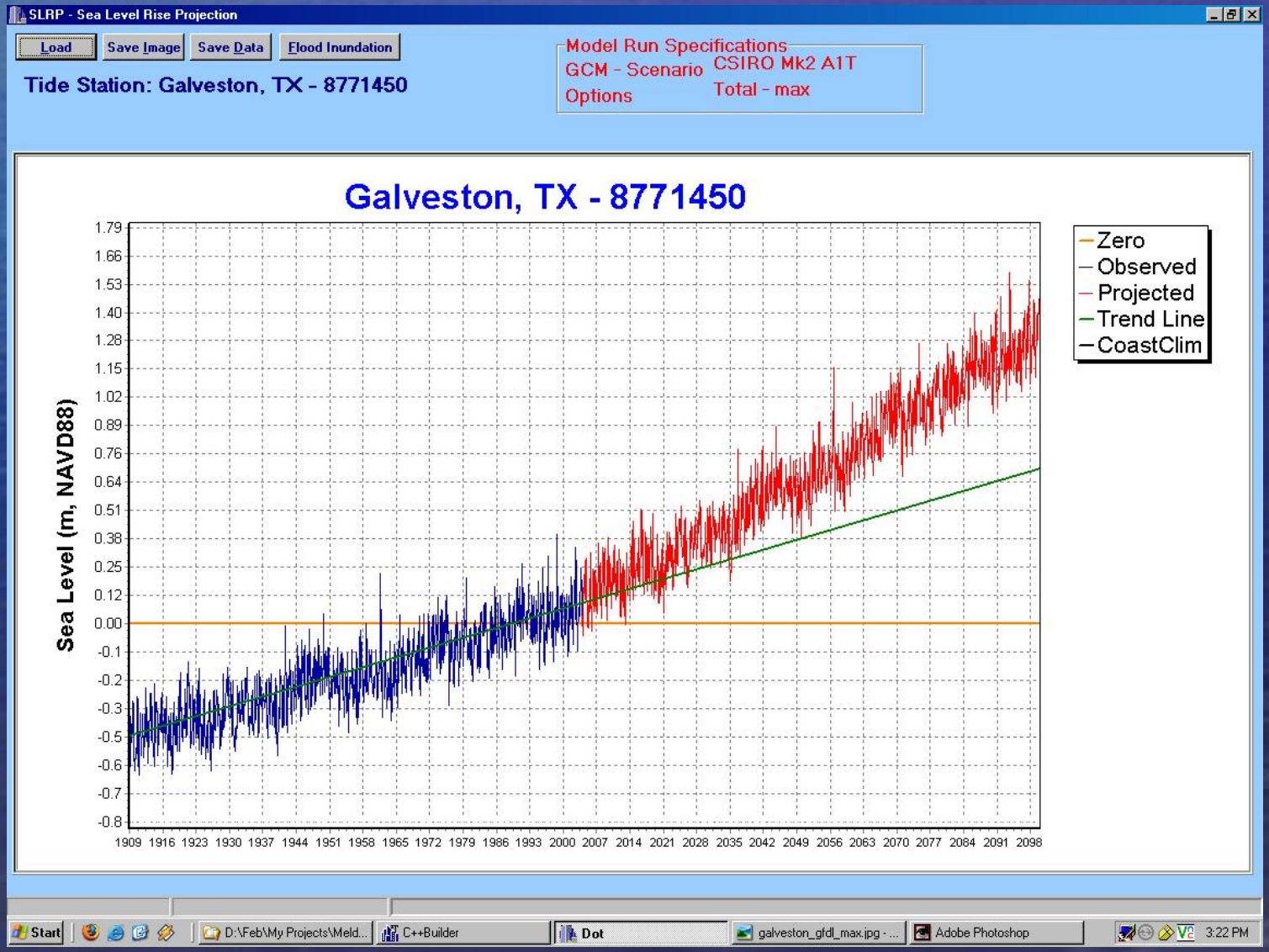
Customized Subsidence and Eustacy Rates

(USGS SLRRP Model, Keim et al. 2008)



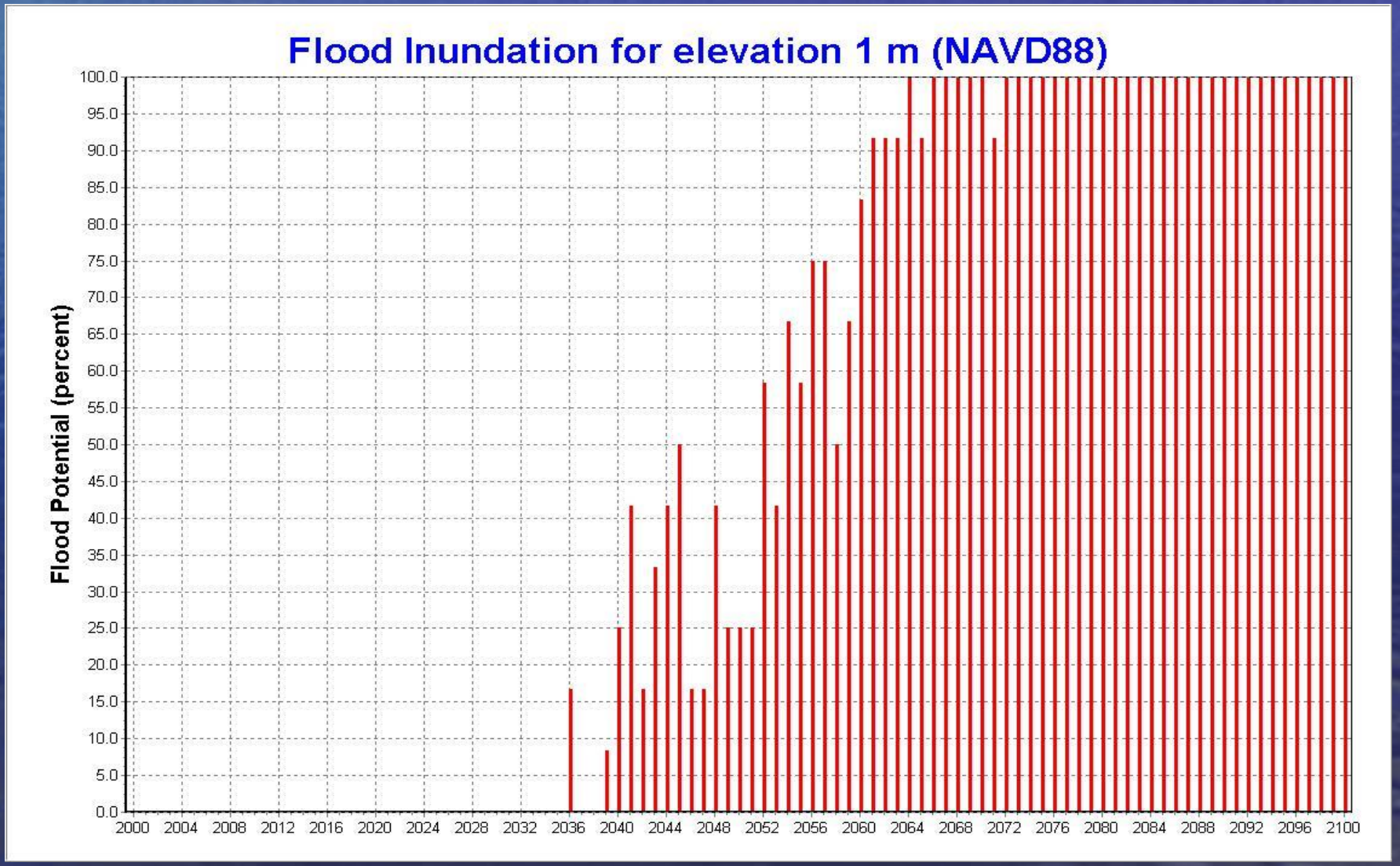
Sea Level Mean Monthly Forecast

(USGS SLRRP Model, Keim et al. 2008)



Seawater Flood Inundation Model

(USGS SLRRP Model, Keim et al. 2008)



USGS

GIS Sea-level Rise Mapping Tools

NOAA Sea-level Viewer

University of Arizona WEB Map Visualization Tool

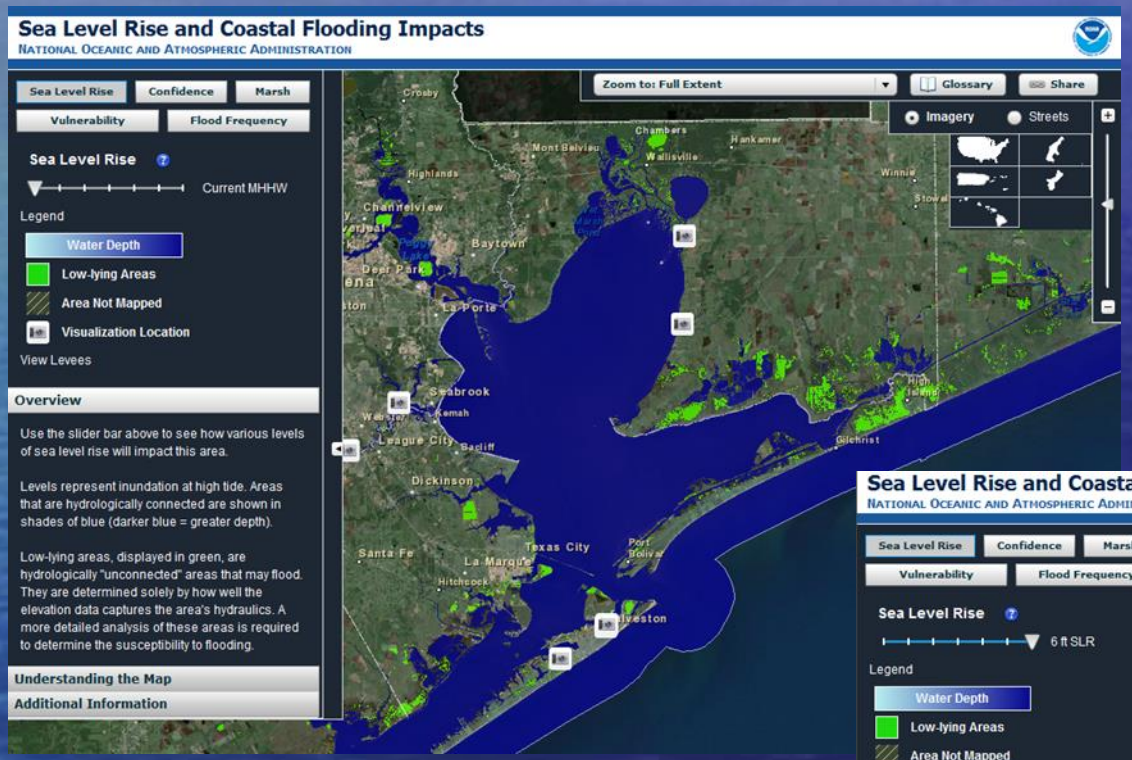
USGS Sea-Level Rise Animations

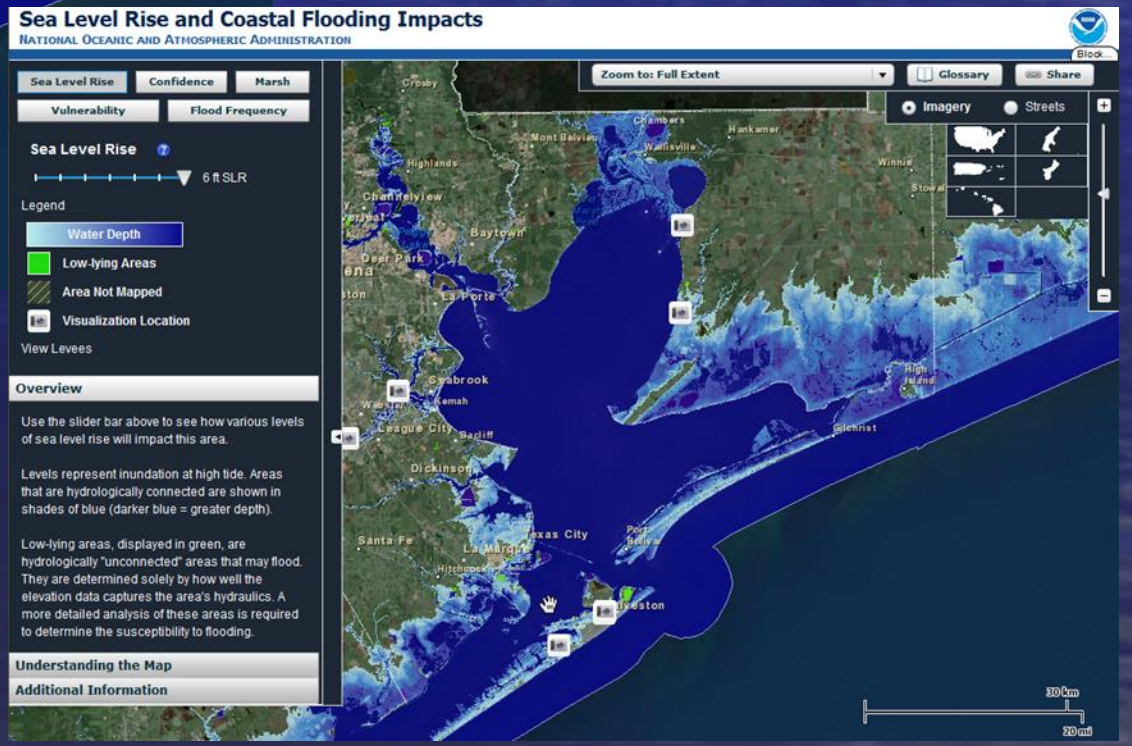
Also known as "Bathtub Models" or visualizations with arbitrary water level (unrectified) such that when water elevation exceeds land elevation, cells are converted from habitat or land classification to submerged open water.

USGS

NOAA Sea-level Viewer

http://csc.noaa.gov/slr/viewer/

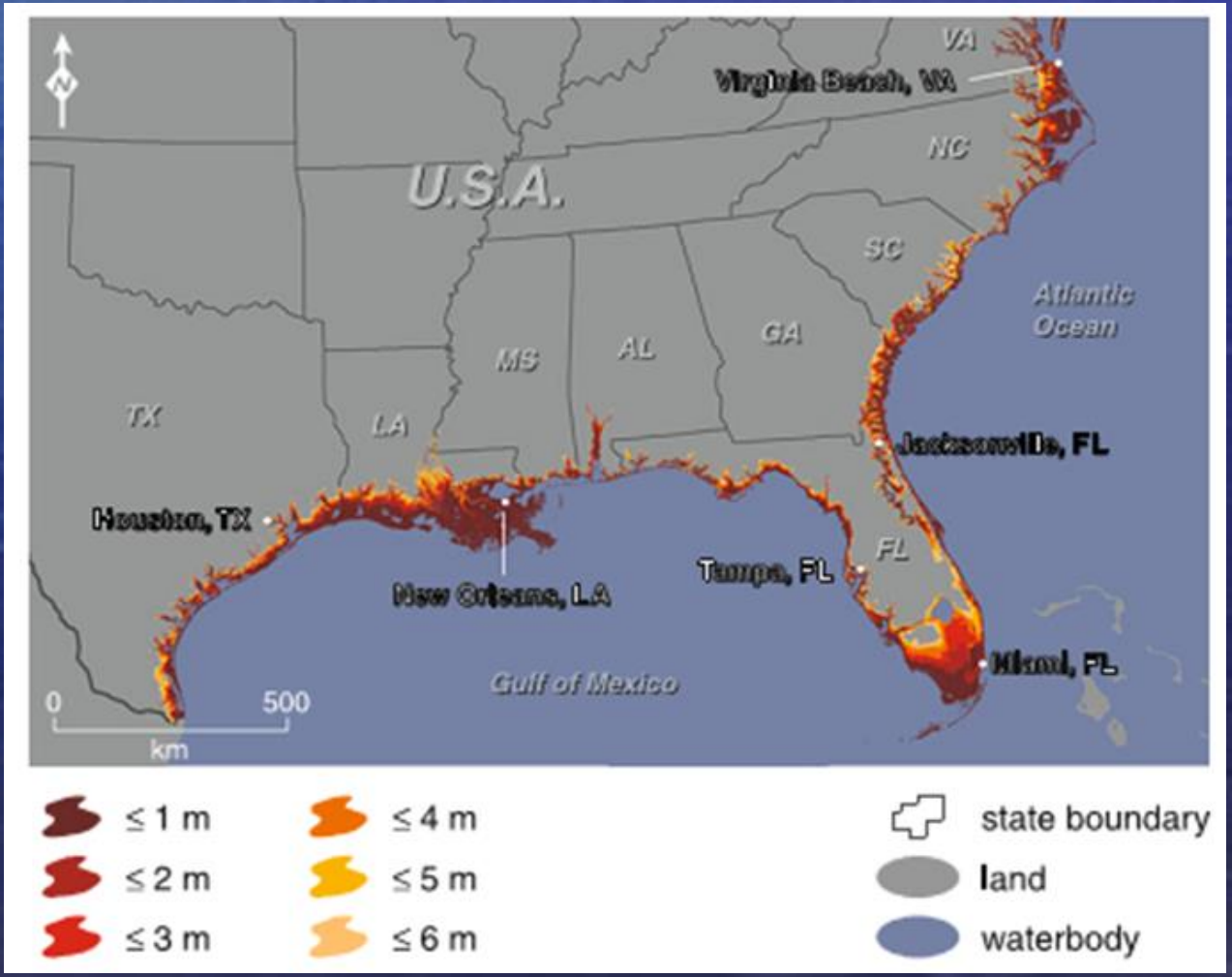




USGS

University of Arizona WEB Map Visualization

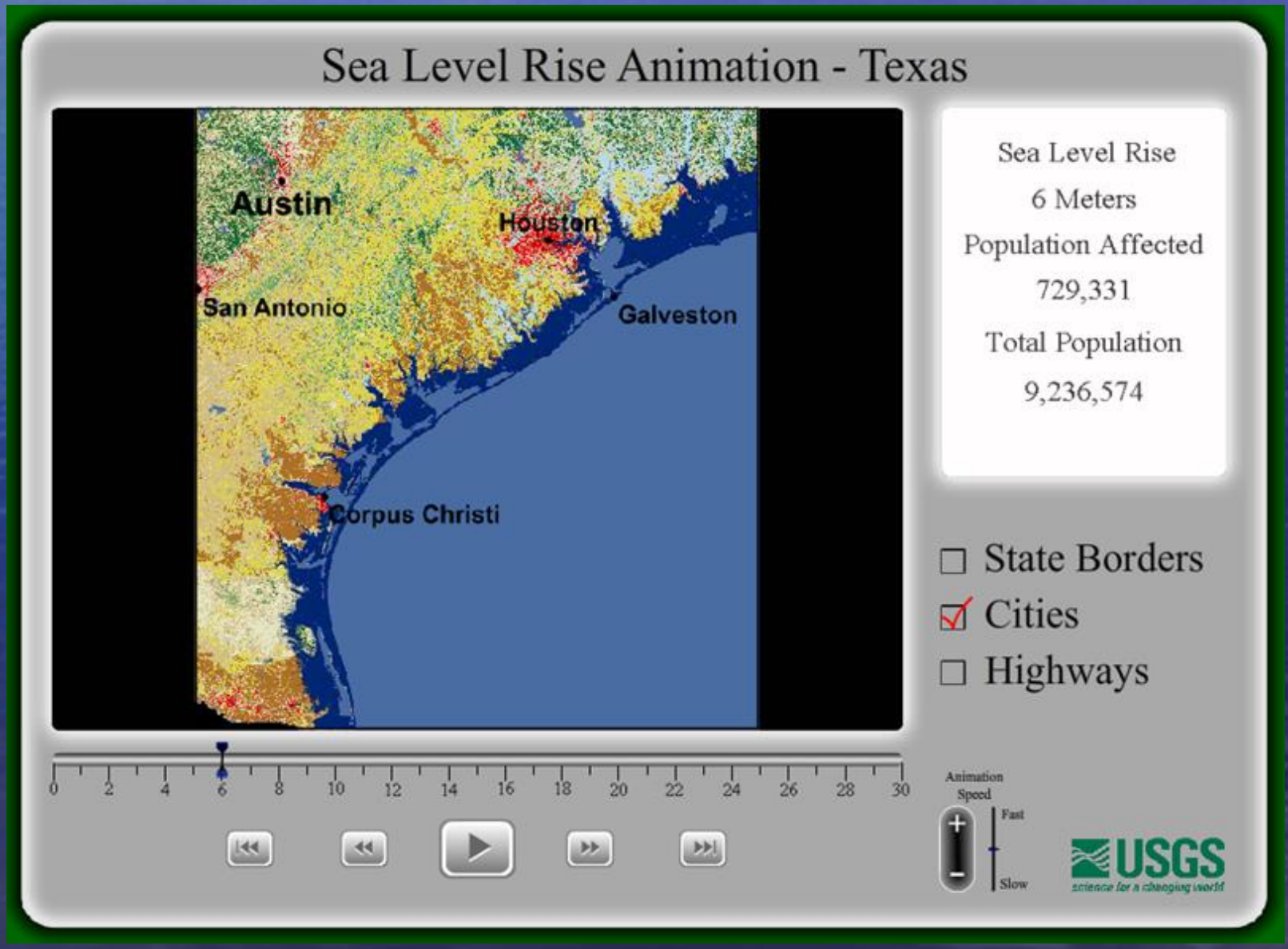
http://climategem.geo.arizona.edu/slr/us48prvi/index.html



USGS

USGS Sea-Level Rise Animations

http://cegis.usgs.gov/sea_level_rise.html



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WETLAND Change Models

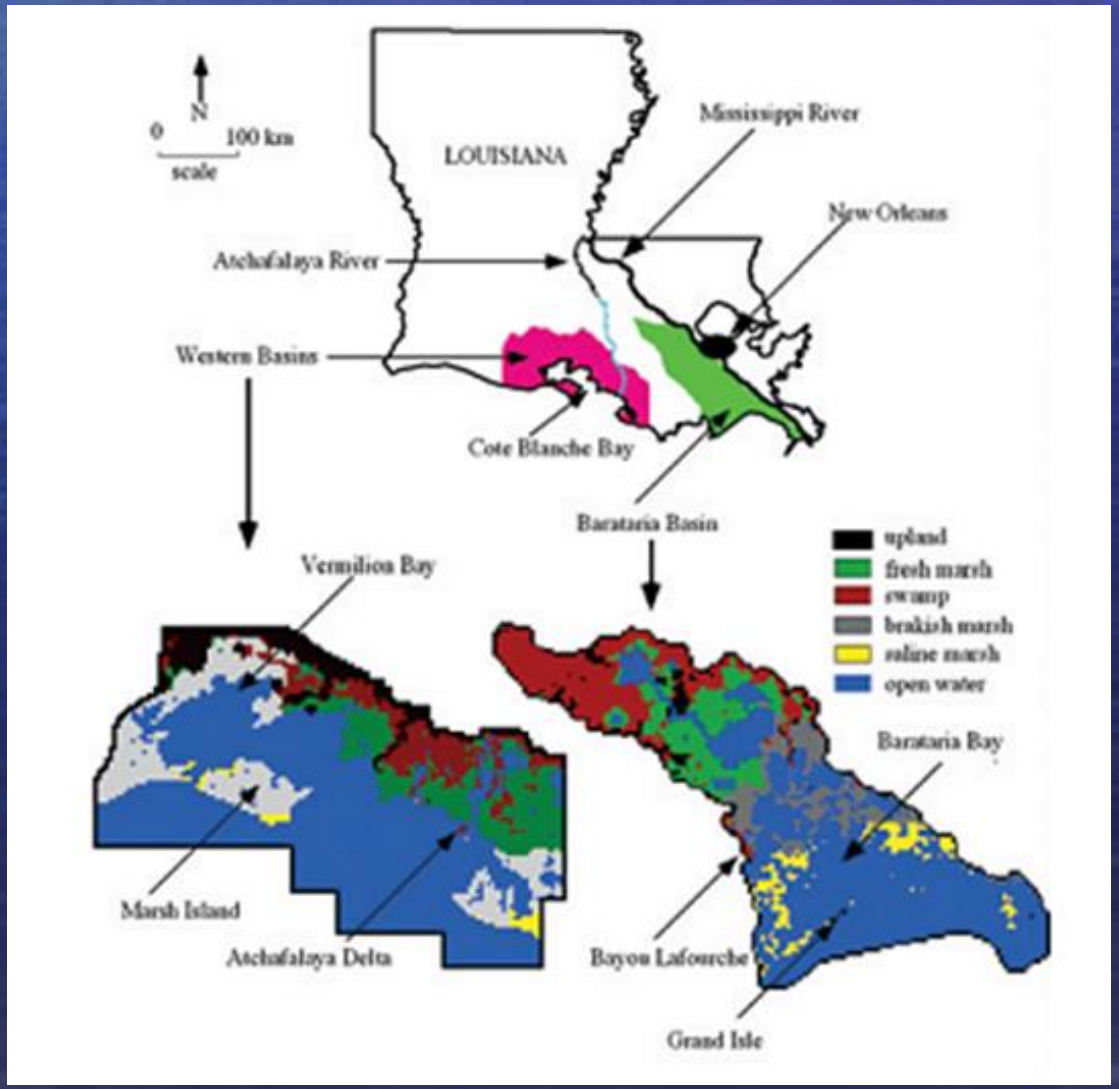
- CELSS, Coastal Ecological Landscape Spatial Simulator
  - Same as BTELSS, Barataria-Terrebonne model application
- SLAMM, Sea-Level Affecting Marshes Model
- SLOPE, Sea-Level Over Proportional Elevation

These models predict habitat or vegetative cover type with change in land surface submergence.

USGS

Coastal Ecological Landscape Spatial Simulator
Barataria-Terrebonne application, BTELSS

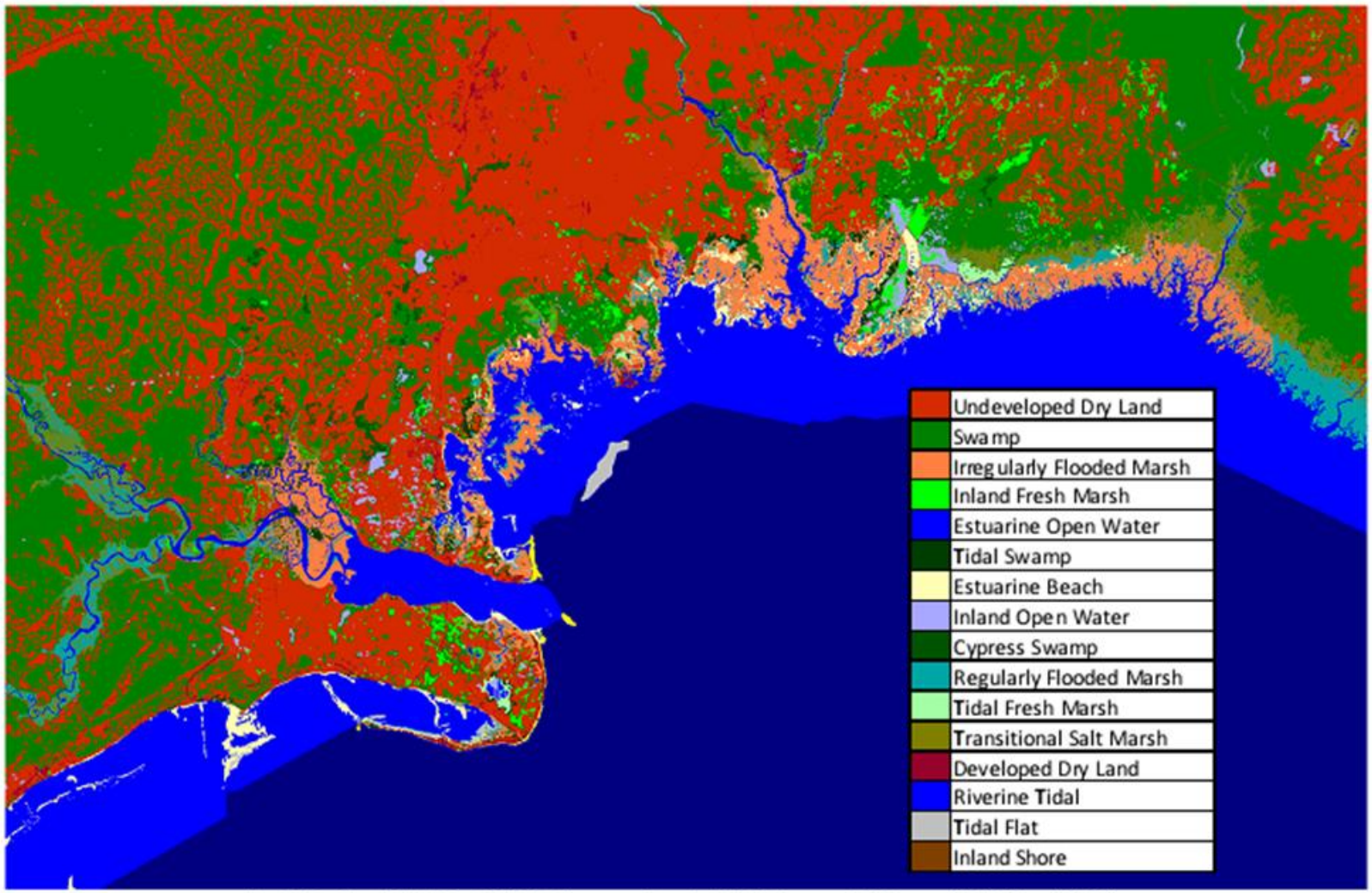
http://www.climateimpacts.org/us-climate-assess-2000/regions/gulf-coast/gulfcoast-chapter7.pdf



USGS

Sea-Level Affecting Marshes Model

http://www.warrenpinnacle.com/prof/SLAMM/



St. Marks NWR, 2100, Scenario A1B Mean, 0.39 m SLR by 2100.

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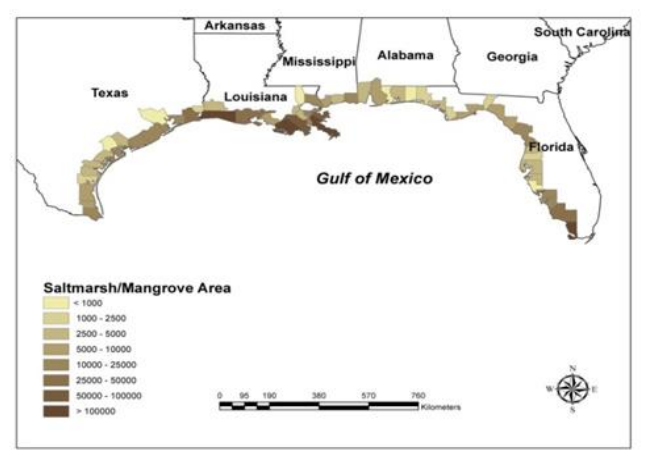
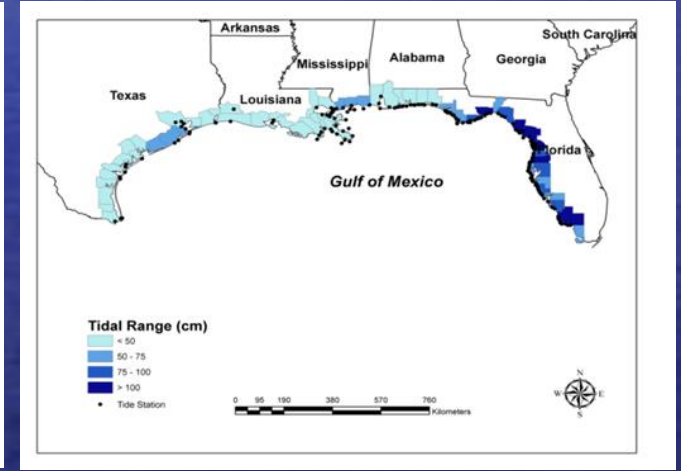
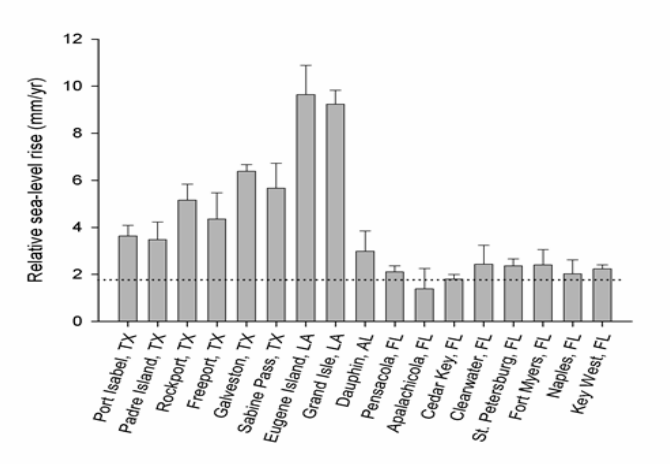
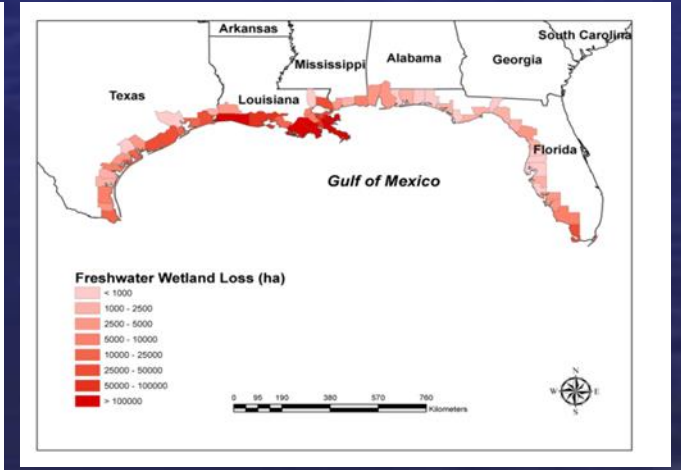
Sea-Level Over Proportional Elevation Model

Doyle et al. 2010









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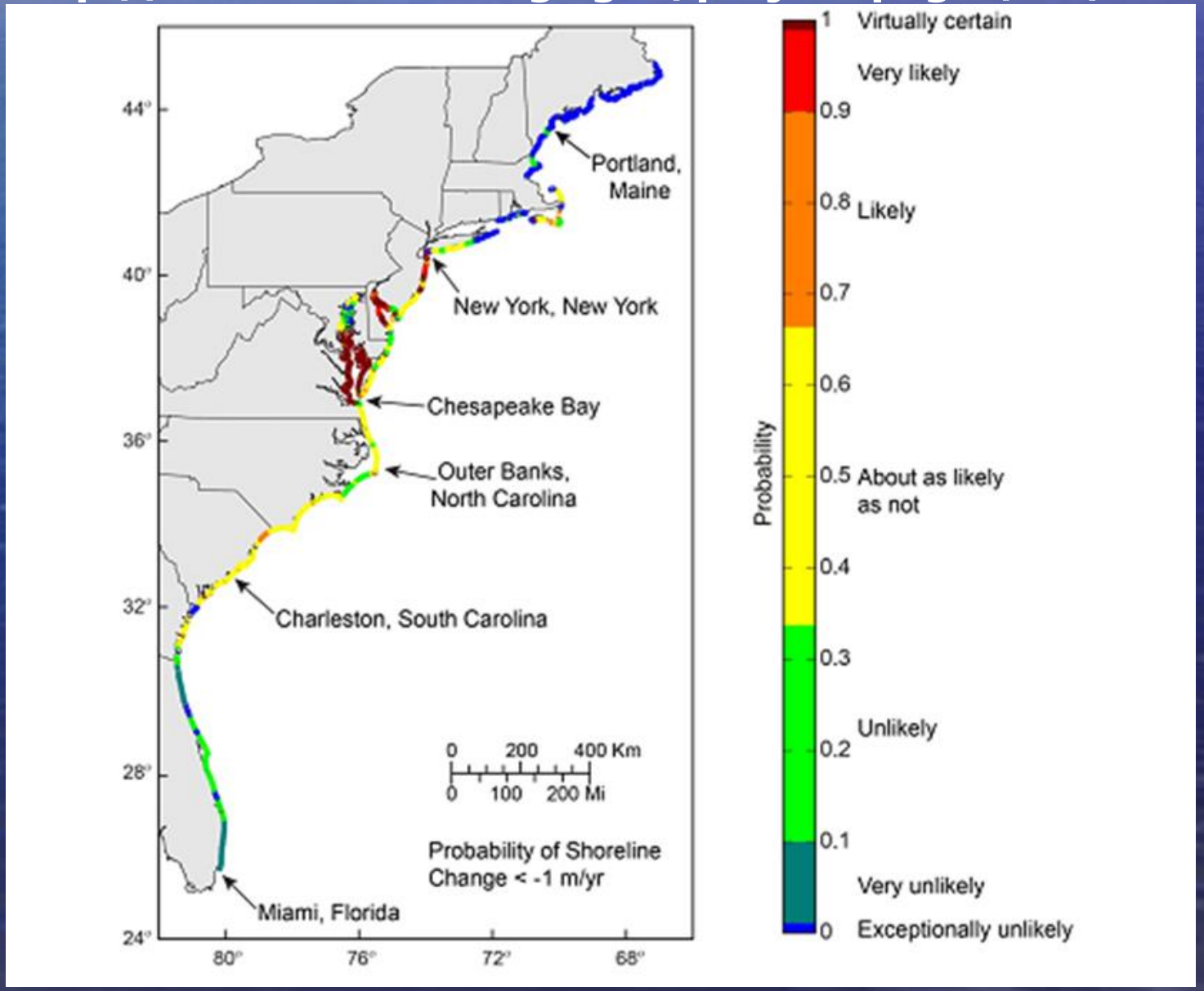
Surface Elevation and Shoreline Erosion Models

- **Coastal Vulnerability Index**
- Marsh Geochronology Methods
- Saltmarsh Stratigraphy and Evolution Models
- **Surface Elevation Tables – SET**
- Tidal Channel Network Models

USGS

Coastal Vulnerability Index

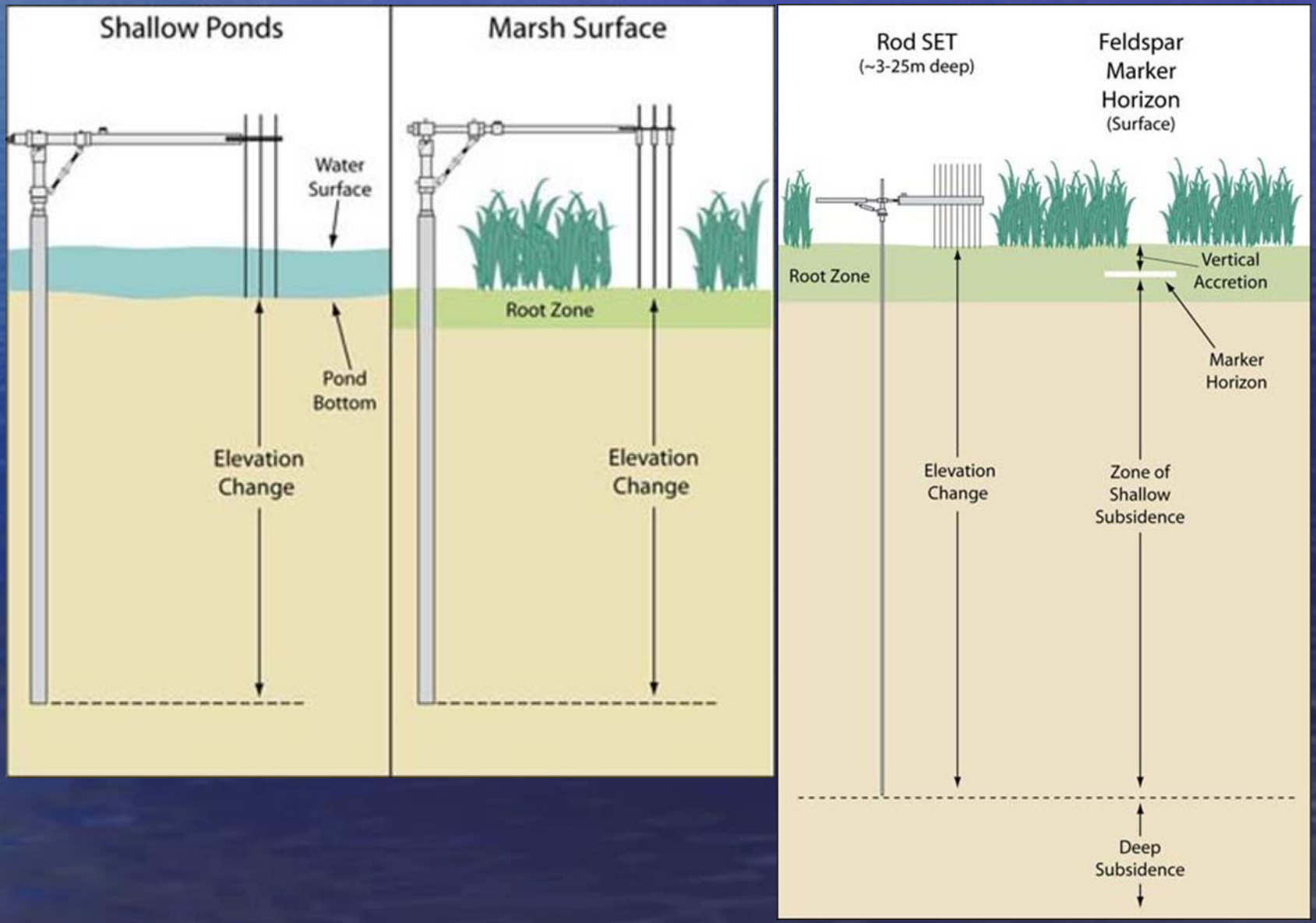
http://woodshole.er.usgs.gov/project-pages/cvi/



USGS

Surface Elevation Table

http://www.pwrc.usgs.gov/set/



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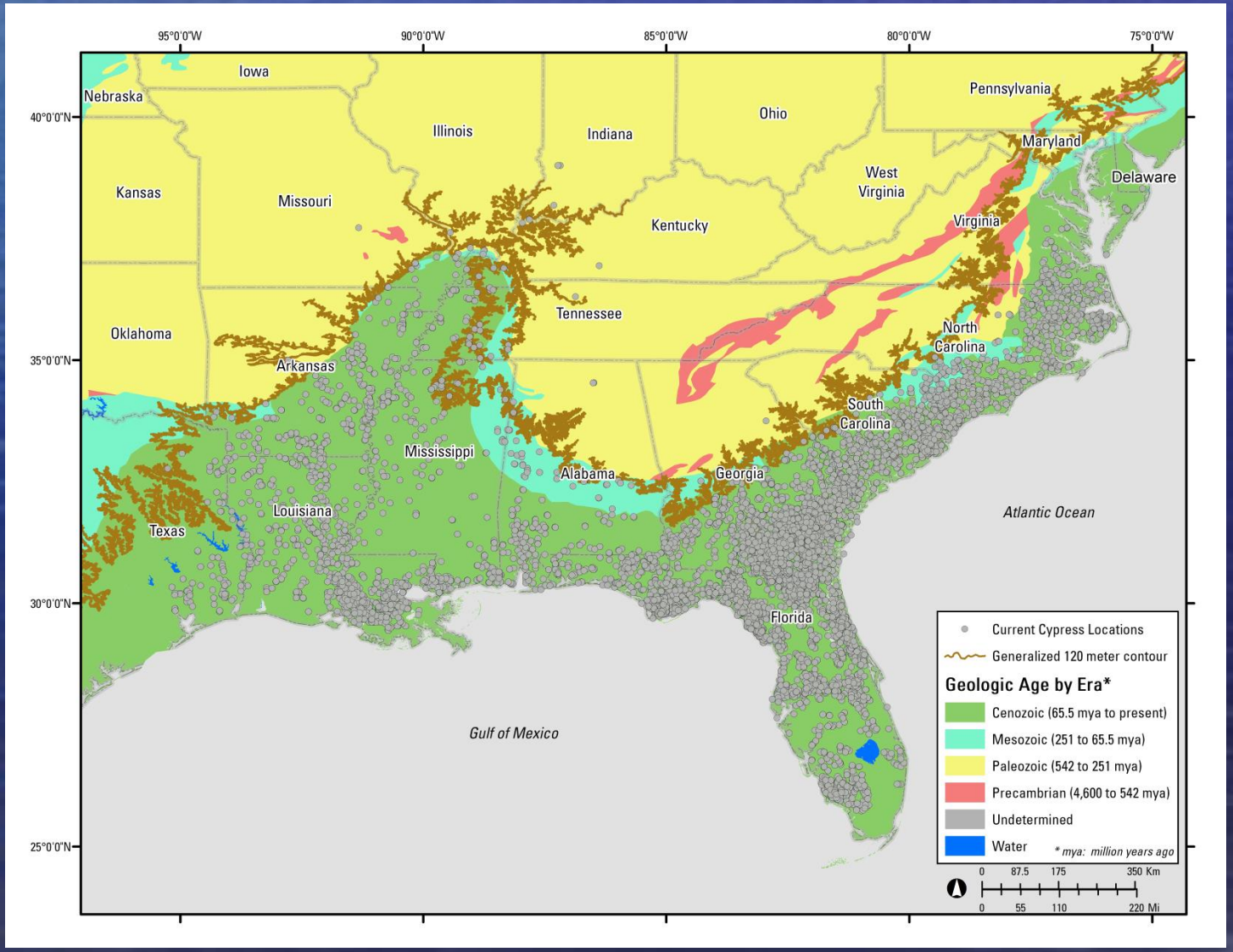
Niche-based Species Distribution Models

Baldcypress Range – Ancient Sea Level



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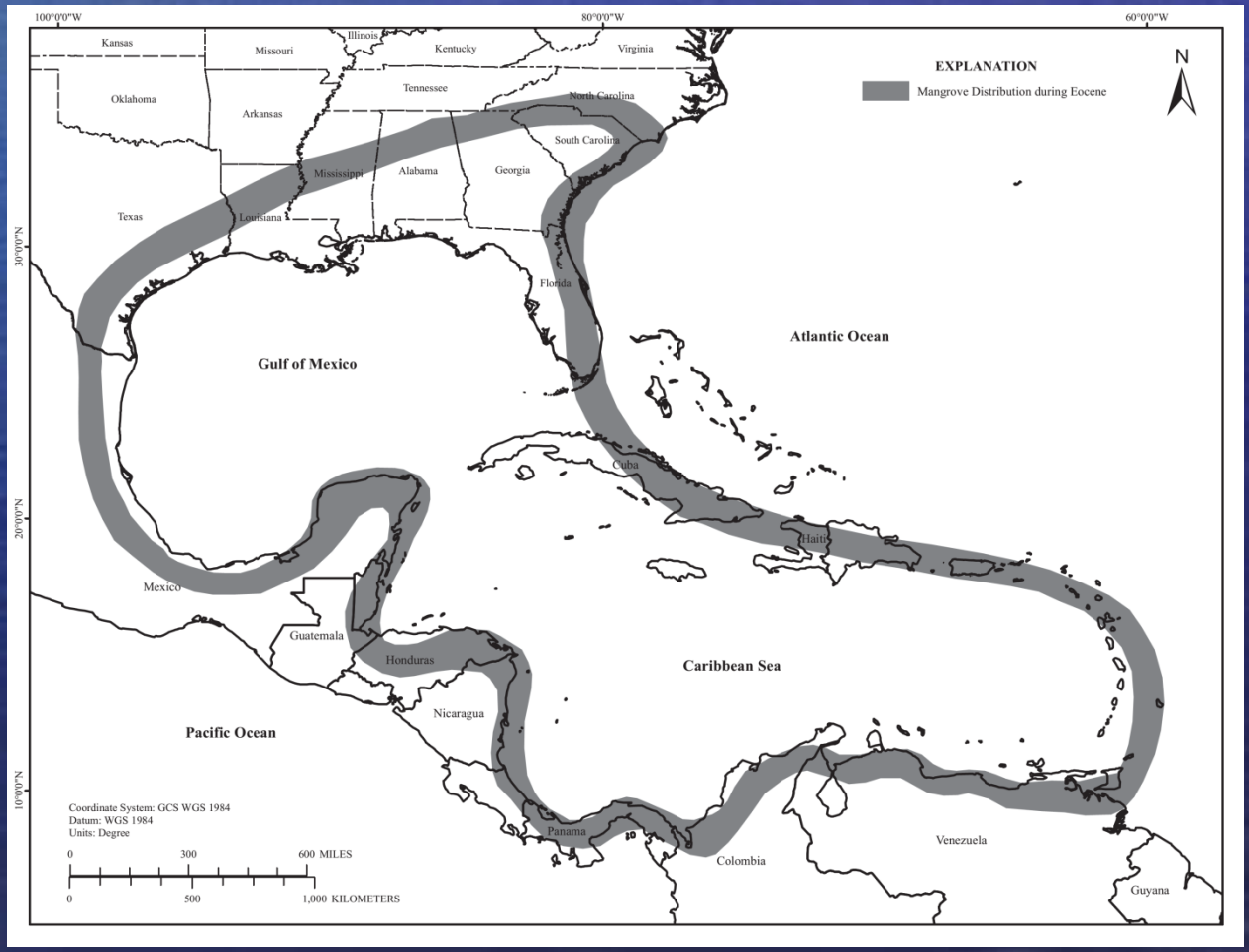
Mangrove Latitudinal Expansion

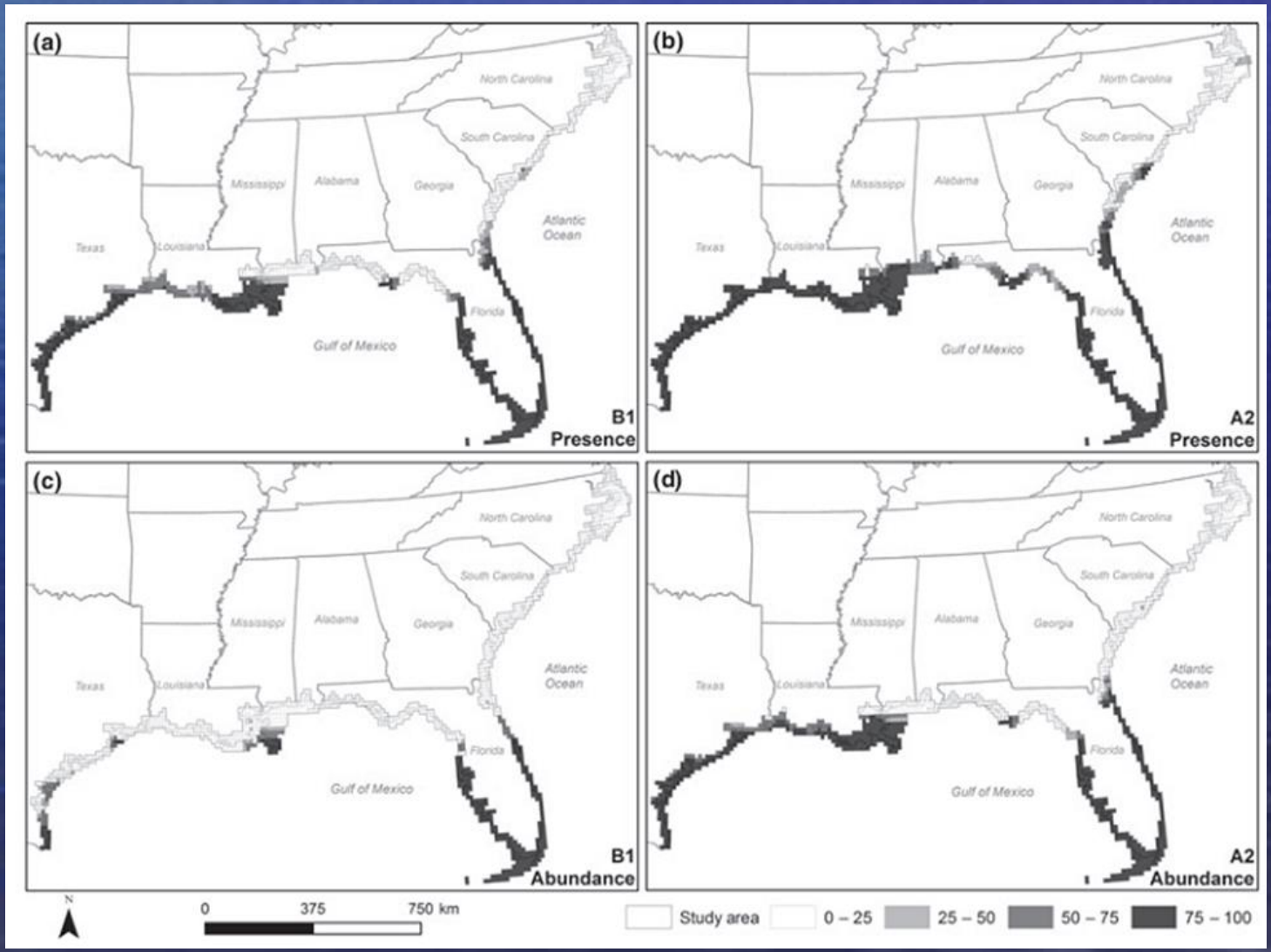
Sherrod and McMillan 1985



USGS

Climate Envelope Mangrove Model

Osland et al. 2013



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Leaf to Landscape Ecosystem Models

- WETLANDS, Species Occurrence by Elevation
- SELVA, Spatially Explicit Landscape Vegetation Analysis
- MANGRO, Mangrove Forest Stand Simulator

Models with predictive measures at the species, organism, or organelle level of ecosystem organization

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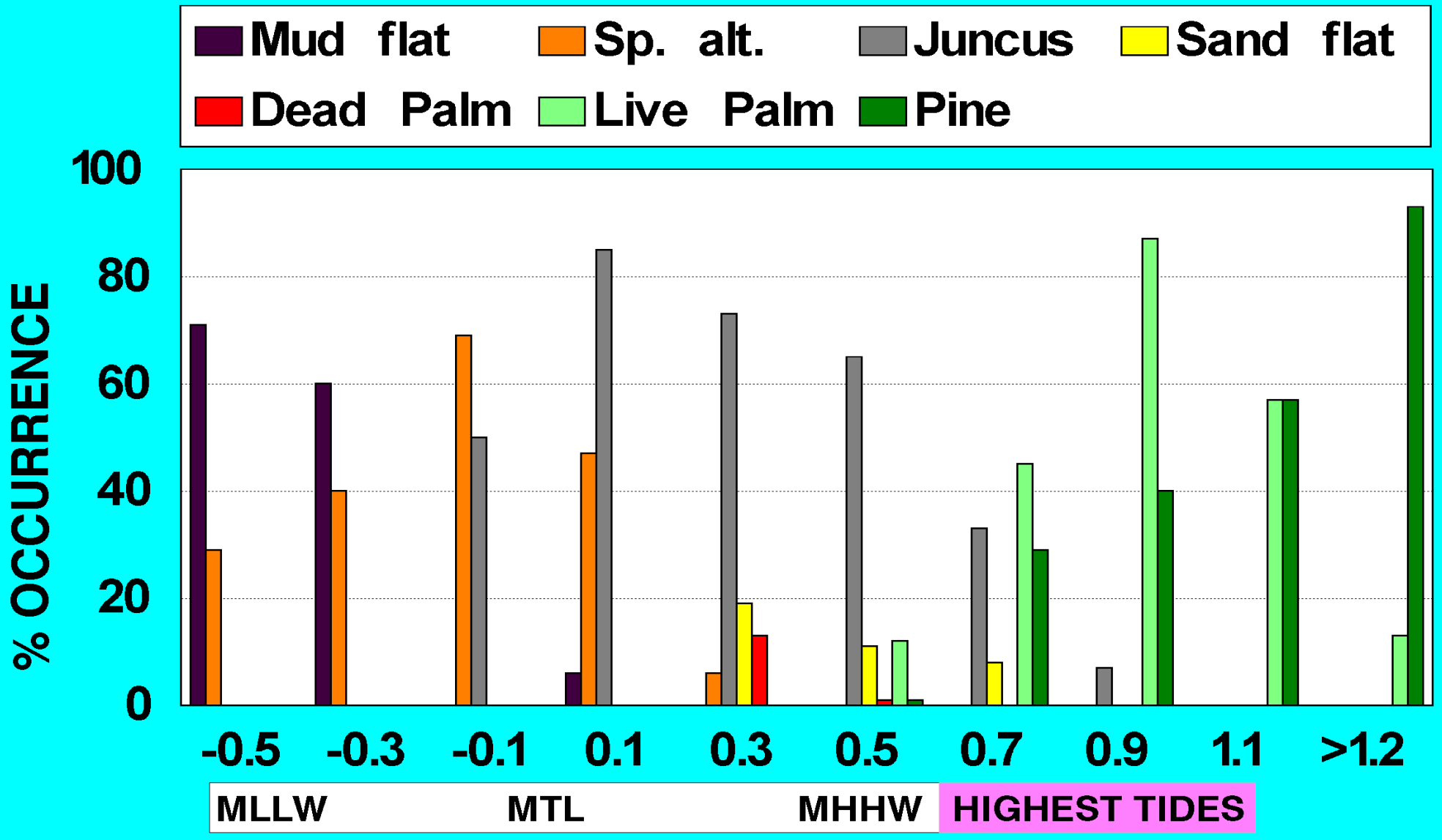
VEGETATION ZONES



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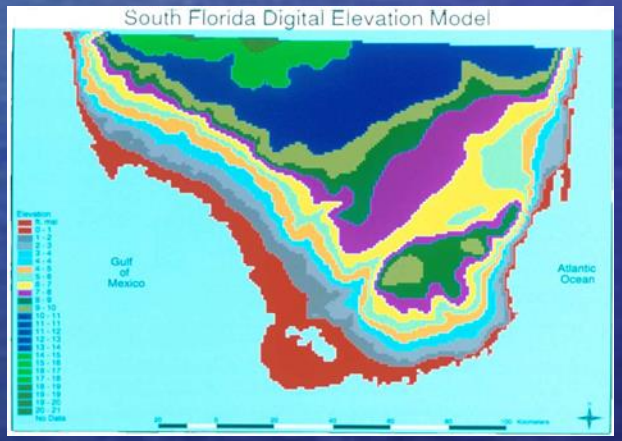
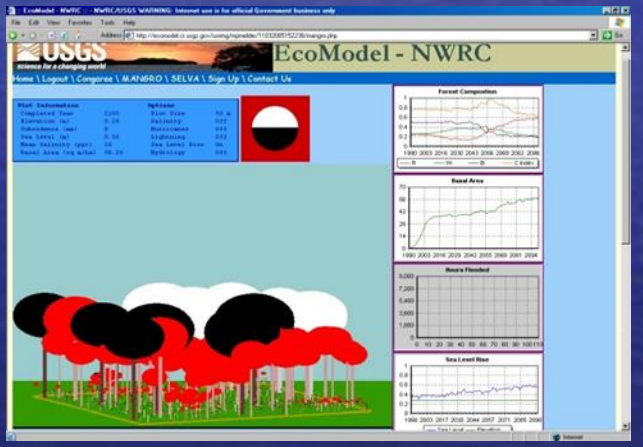
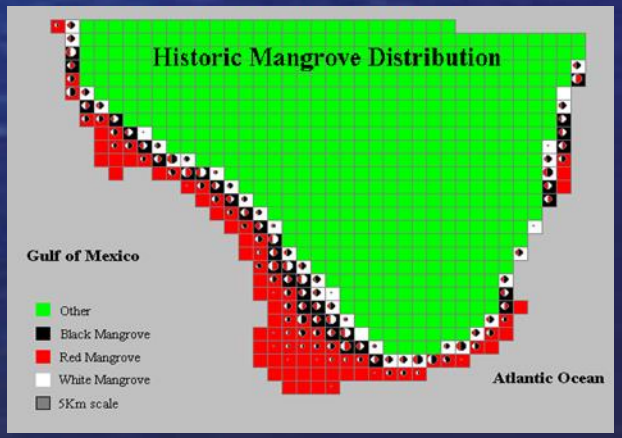
Doyle et al. 2003

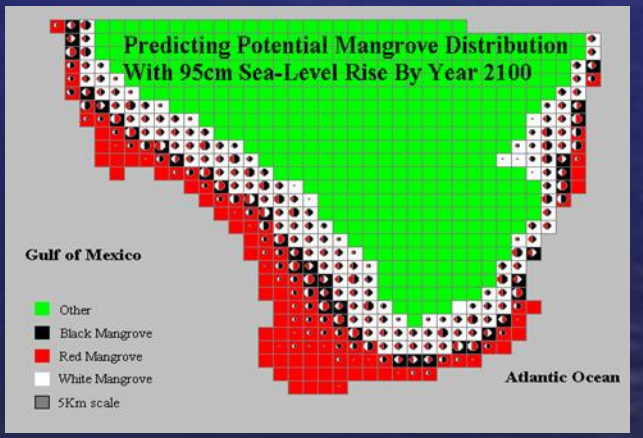
SELVA-MANGRO SLR Application

Doyle et al. 2003









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Questions!

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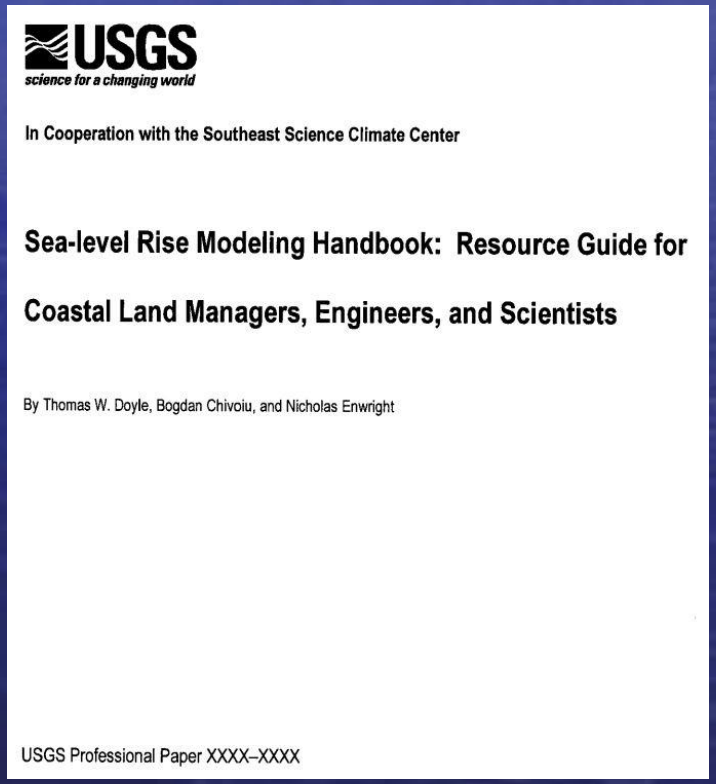
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In Cooperation with the Southeast Science Climate Center

Sea-level Rise Modeling Handbook: Resource Guide for Coastal Land Managers, Engineers, and Scientists

By Thomas W. Doyle, Bogdan Chivoiu, and Nicholas Enwright

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